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AEROSPACE ENGINEERING

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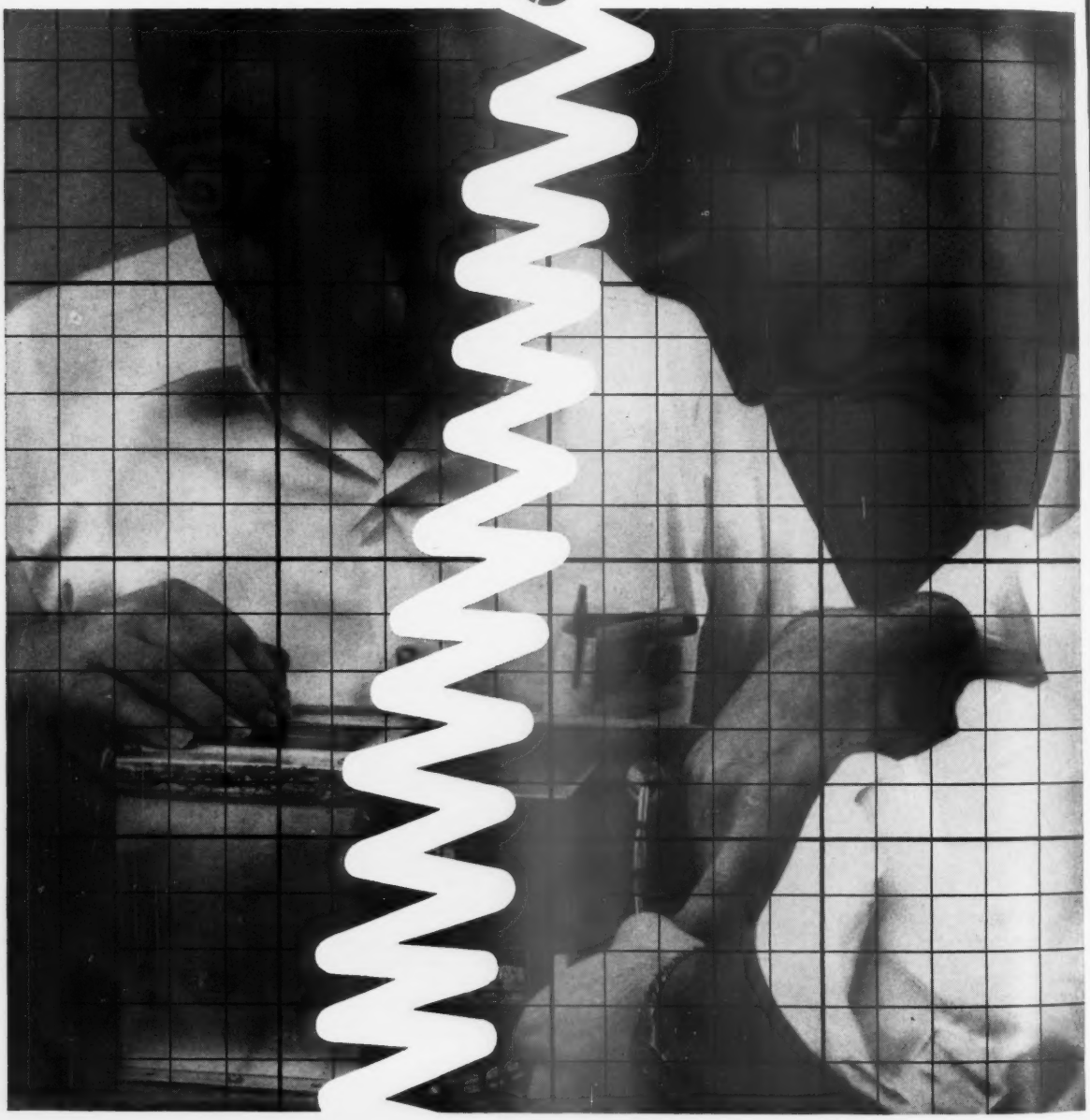

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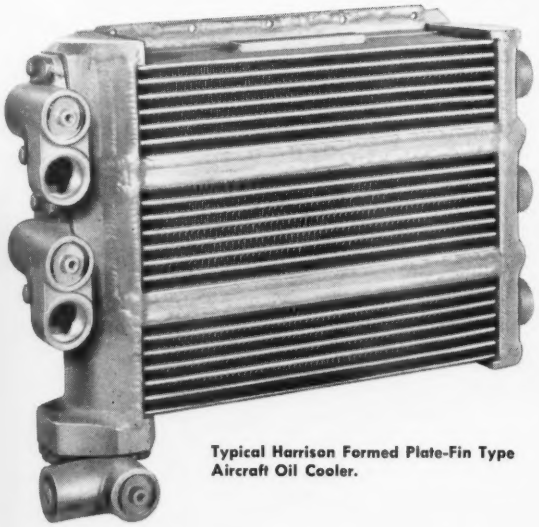

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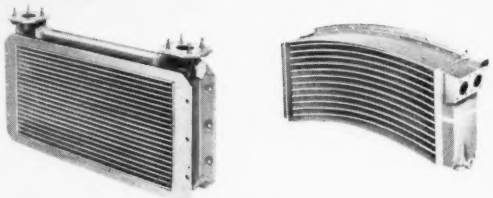

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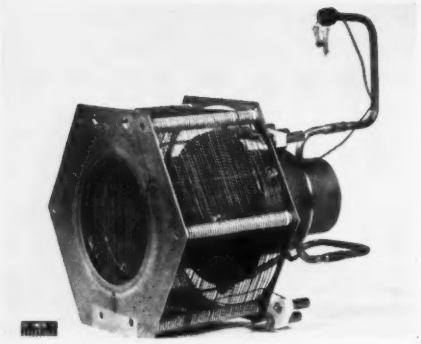

ON OUR COVER . . .

A study on "Electric Propulsion for Space Flight," providing this cover photo, has been prepared exclusively for Aerospace Engineering by NASA Scientist William R. Mickelsen. The article begins on page 6. Illustrated: A development from recent research—an experimental electron-bombardment ion rocket engine.

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AEROSPACE ENGINEERING

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VOLUME 19 / NUMBER 11 **November 1960**

Featured in this issue

Editorial **5** Cooperation vs. Competition (II)

William R. Mickelsen, Lewis Research Center, NASA **6** Electric Propulsion for Space Flight

D. J. Blakeslee, MIAS, The RAND Corporation **12** Empirical Relationships for Jet-Flap Lift and Drag Prediction

J. C. Armstrong, R. W. Flados, and W. T. McKenzie, MIAS, Convair-Fort Worth, A Div. of General Dynamics Corp. **16** Simulated Flight Testing of a Cowled Turbojet Engine by Use of an Exhaust Ejector

L. W. Warzecha, AFIAS, General Electric Company **18** Performance and Design Considerations for Maneuvering Space Vehicles

Frederick L. Ryder, MIAS, Republic Aviation Corporation **24** Anticipating Anti-Skid System

Kermit L. Sandefur, Hycon Mfg. Company **28** Space Reconnaissance

Richard W. Skulski, The Martin Company **32** Support Systems: Part III—In the Future

Departments

62 IAS Papers

65 Reviews

75 International Abstracts

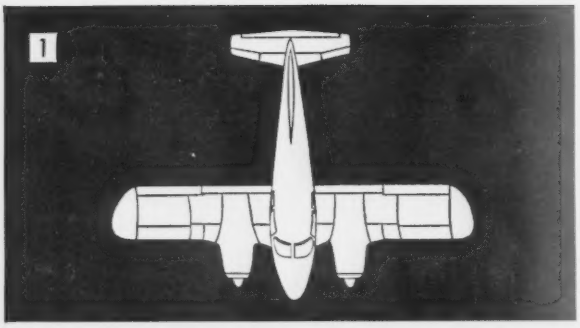
102 Fairchild Publication Papers

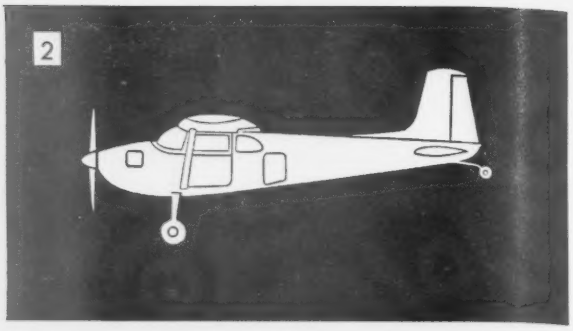
102 Special IAS Publications

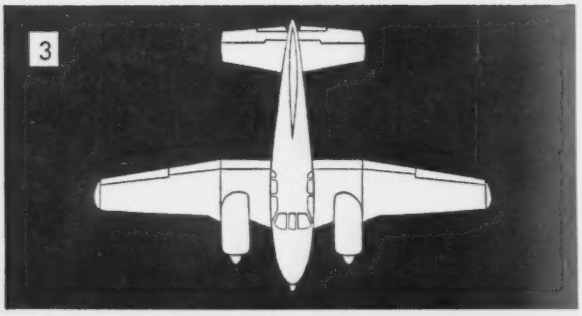
103 Books

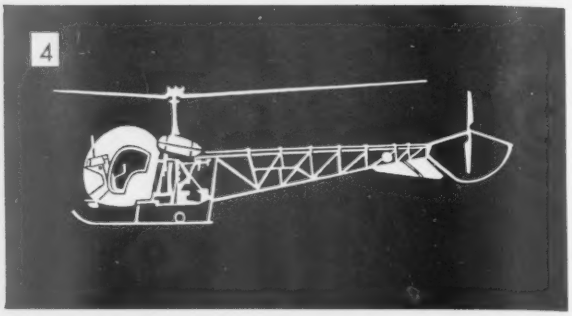
105 Personnel Opportunities

106 Index to Advertisers









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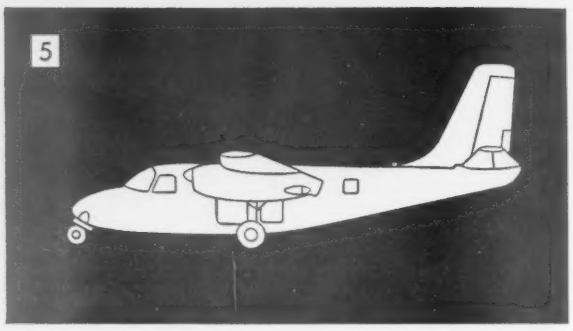

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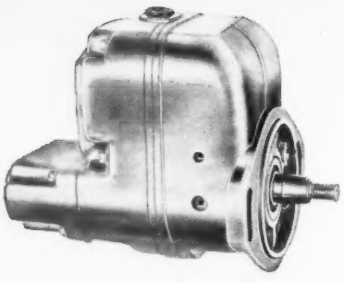

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EDITORIAL

Cooperation vs. Competition (II)

Almost fifteen years ago an editorial appeared in the then Aeronautical Engineering Review under the above title. It suggested that the best interests of all would be served by more collaborative action among professional and scientific societies. We stated our position at that time as follows: "We can, by working cooperatively with other groups whose primary interests are in other activities, bring combined experience to bear for the mutual benefit of all concerned. . . .Competition among professional societies leads only to wasteful duplication of effort and to confusion among their members. The Institute will welcome any suggestions from its members or from other societies which will promote cooperation rather than competition."

During the intervening years, the theme has been repeated many times and demonstrated many times in practical form by the inclusion of joint sessions with other societies in many IAS programs. Such collaboration has taken place at all levels—National, Regional, and Sectional. Among the groups with whom we have worked have been the American Society of Mechanical Engineers, the American Helicopter Society, the American Meteorological Society, the American Physical Society, the American Rocket Society, the Aerospace Medical Society, the Instrument Society of America, the Institute of Radio Engineers, and many others. Wherever mutuality of interest seemed to exist, collaborative action has been undertaken.

With the broadening of the base of professional interests among IAS members and the corresponding broadening of all IAS activities to enable us to serve the professional needs of our members, opportunities for cooperative activity have been extended. Our Aerospace Technology Panels have a combined membership of well over 150 of the top professional men in the country in fields ranging the whole spectrum of the Aerospace Sciences. (Present Panel coverage includes Aerodynamics and Fluid Mechanics; Aeroelasticity; Biomedical Sciences; Communication; Control, Guidance, and Navigation; Energy Conversion; Flight Mechanics; Instrumentation; Meteorology; Nuclear Applications; Operations; Propulsion Systems; Space Physics; Structures and Materials; Vehicle Design.) Our Planning Committees at all levels have the benefit of the best advice that can be had in providing programs geared to IAS members' requirements. The IAS is thus in a very strong position not only to serve the needs of its own members in the areas of its own interests but also to work cooperatively with other groups where common interests are involved. We have long since been committed to such a policy, and our Council's intention is clearly that it should continue thus.

At the June 29 meeting of the Council in Los Angeles, a proposal was put forward via the Los Angeles Section that some sort of collaborative effort be undertaken with respect to the scheduled 1961 IAS Summer Meeting and a proposed meeting of the American Rocket Society for about the same period. After considering the matter at length, the Council agreed that overall time and effort might be saved by some degree of joint planning for this particular case. Some practical difficulties were anticipated, but it was felt that the effort was justifiable and that as a result some guide lines for future activities might emerge. Specifically, the Council made the following alternative proposals:

(1) Each society schedule three days of meetings in the same week, with one day overlap in the middle of the week as a joint meeting of the two societies.

(2) Both societies hold concurrent meetings in the same city and select one day on which to hold joint sessions.

(3) ARS cosponsor one day of technical sessions at the regular IAS Summer Meeting.

During the past few months several meetings have been held with the Los Angeles representatives of the two societies, and agreement has been reached that the first proposal above be adopted. Work is now under way toward building the separate and combined technical programs, and consideration is being given to proper physical environment for the meeting.

A brief progress report on this activity was made in the IAS Executive Committee Meeting in New York on October 11. Consensus was that the project was well worth the effort and that results would be watched with great interest.

Our basic policy was reconfirmed—that wherever mutuality of interest exists in areas of professional development, more is to be gained by collaboration than by competition. SPJ

Electric Propulsion for Space Flight

William R. Mickelsen, Lewis Research Center, NASA

THE POTENTIAL ADVANTAGES of the acceleration of electrically charged particles to obtain thrust were recognized in 1906 by Dr. Robert H. Goddard and in 1929 by Prof. Herman Oberth.[1] It was evident that a serious shortcoming of chemical "fire" rockets is the enormous rate of propellant consumption $\dot{m}$ required to obtain sufficient thrust T, since

$$T = \dot{m}v \tag{1}$$

where v is the exhaust velocity. For thermodynamic and chemical reasons alone, it appears that the exhaust velocity of the chemical rocket is limited to less than about 5,000 m./sec. so that the chemical rocket will continue to require large amounts of propellant for long flights in space. In direct contrast, the exhaust velocity of the electric rocket is theoretically limited only by the speed of light since charged particles can be accelerated to very great velocities by electric or magnetic fields.

The substantial reduction in propellant weight offered by the electric rocket is somewhat offset by higher electric power requirements as exhaust velocity is increased. The propellant mass M_{pr} can be written

$$M_{pr} = \dot{m}t_p = Tt_p/v \tag{2}$$

and the power plant mass is

$$M_{pp} = \alpha P = (1/2)\alpha Tv \tag{3}$$

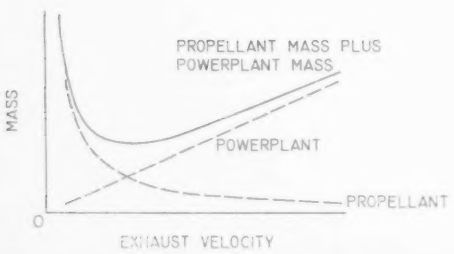

Fig. 1. Propellant and power-plant mass for fixed thrust, propulsion time, and power-plant specific mass.

Mr. Mickelsen is Head of the Ion Propulsion Section at the NASA Lewis Research Center. He received a B.S. (Mech. Eng.) from the University of Wisconsin in 1948 and an M.S. (Aero. Eng.) from the Case Institute of Technology in 1953. He was a recipient of a Rockefeller Public Service Award in 1958, under which he did advanced study at the University of Cambridge for a year. Mr. Mickelsen joined the staff of the Lewis Research Center (then under NACA) in 1948, and has done research in turbulent combustion, turbulent diffusion, rocket screaming, and electric propulsion.

where t_p is the propulsion time, P the output power, and α the specific mass of the power plant (kg./kw.). By plotting propellant and power-plant masses (for fixed T, t_p, and α) against exhaust velocity and summing these masses as in Fig. 1, it can be seen that overall mass reduction is limited by increases in power-plant mass. As electric power plants become lighter, it is evident that the overall mass reductions offered by electric propulsion will become more pronounced.

With the advent of practical nuclear fission power sources, lightweight electric power plants became possible. In a number of excellent papers, Shepard and Cleaver[2] and Stuhlinger[3–8] have shown that electrically propelled spacecraft with nuclear-turboelectric power plants are quite feasible and promise to be considerably lighter than conventional rockets for interplanetary space missions. More recent mission analyses and vehicle design studies, discussed in the next sections, have shown that electric propulsion promises high performance for space missions ranging from Earth satellite orbit adjustment to manned space flight and deep space instrumented probes. Considerable research has been done on the electric rocket engine, and the status of these propulsion units is described in later sections. Most of the material is based on work done at the Lewis Research Center; a summary of other work is beyond the scope of the present paper.

A brief history of electric propulsion is outlined, together with some fundamental relations necessary to the description of electric rocket principles. The salient features of electric spacecraft mission analysis are listed, and some recent advances in fast interplanetary flight paths are discussed. Examples of electric power-plant and vehicle design studies are presented. Electrothermal, plasma, and ion rocket engines are described in detail, and their research and development status is discussed.

Mission Analysis

As implied by the preceding discussion, the space mission, the power-plant specific mass, and the thrust dictate the optimum exhaust velocity for maximum payload capacity of electrically propelled spacecraft. Although exact mission analysis is very complex, some simple approximate relations can serve to illustrate the effect of the mission, the thrust, and the exhaust velocity on the payload capacity. In 1957, Moeckel[9] pointed out that the optimum exhaust velocity for maximum payload capacity could be obtained from a simple summation of vehicle components

$$M_0 = M_{str} + M_{pay} + M_{pp} + M_{pr} \qquad (4)$$

where M_0, M_{str}, and M_{pay} are the total initial, the structure, and the payload masses. Using the previous relations for power-plant and payload mass [Eqs. (2) and (3)],

$$\frac{M_{pay}}{M_0} = 1 - \frac{M_{str}}{M_0} - \frac{\alpha}{2}\frac{T}{M_0}v - \frac{Tt_p}{M_0}\frac{1}{v} \qquad (5)$$

From this relation, it is evident that, for a given mission t_p and exhaust velocity, the thrust-to-weight ratio T/W_0—i.e., vehicle acceleration—and the power-plant specific mass must be small enough so that the payload-

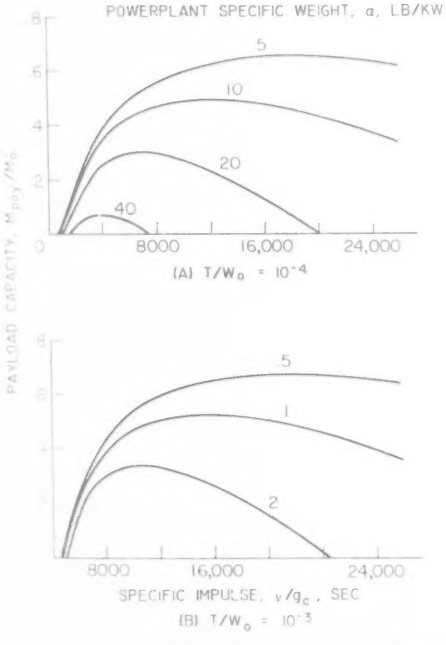

Fig. 2. Payload capacity of electric spacecraft for minimum-energy Mars round trip (with constant power during propulsion times and with negligible structure weight).[10]

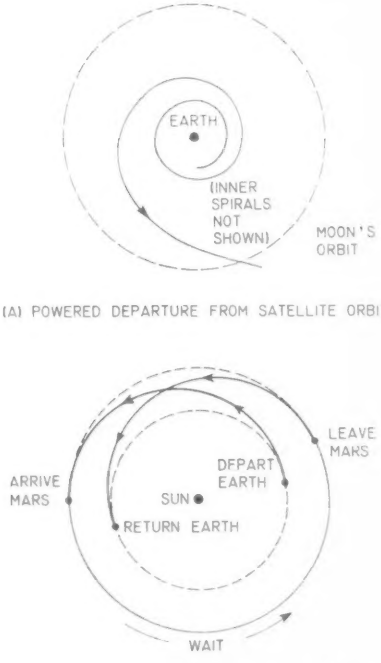

Fig. 3. Minimum-energy low-thrust trajectory for Mars round-trip mission.[9]

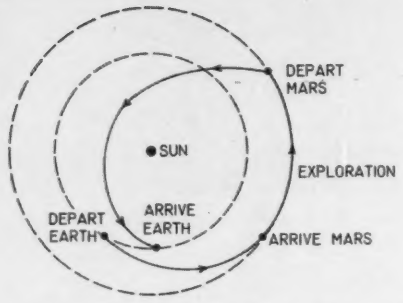

Fig. 4. Moeckel's fast indirect trajectory for Mars round trips.[11]

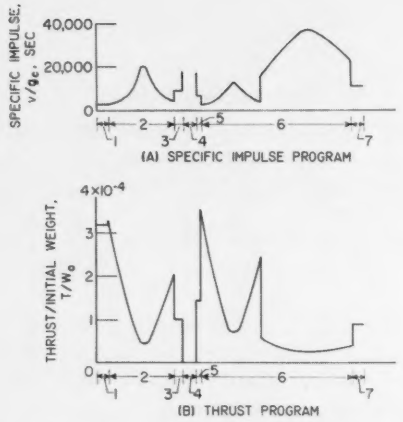

Fig. 5. Specific impulse and thrust programs for 500-day Mars round trip with Moeckel's fast indirect trajectory; $\alpha = 10$ lbs./kw. and $W_{pp}/W_0 = 0.2$. (1) Escape Earth, (2) Earth-Mars transfer, (3) Mars descent, (4) exploration, (5) escape Mars, (6) Mars-Earth transfer, and (7) Earth descent.[11]

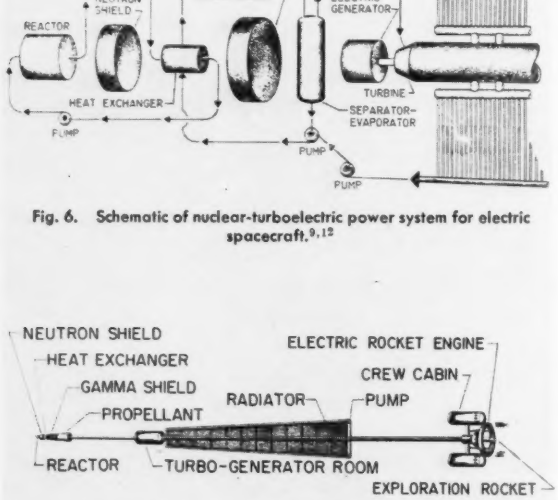

Fig. 6. Schematic of nuclear-turboelectric power system for electric spacecraft.[9,12]

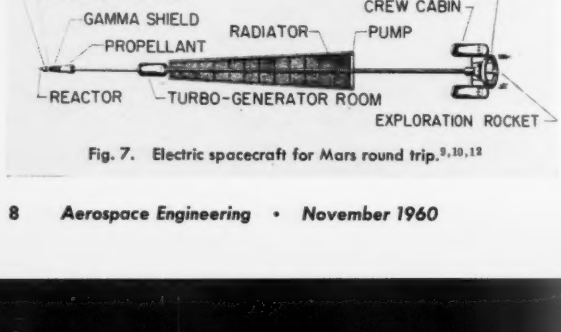

Fig. 7. Electric spacecraft for Mars round trip.[9,10,12]

to-total-mass ratio is greater than zero. For a minimum-energy round trip to Mars, this effect has been demonstrated by Moeckel[10] as shown in Fig. 2, where the payload capacity is plotted against specific impulse v/g_c (g_c = 32.2 ft./sec.^{2} = 9.81 m./sec.^{2}). From this figure, it can be seen that with a power-plant specific weight of 40 lbs./kw. (generator output power), a vehicle with very small payload could make the trip with $T/W_0 = 10^{-4}$ but not with $T/W_0 = 10^{-3}$. As will be seen later, α = 10 lbs./kw. is a reasonable estimate for power plants based on present technology; so, with $T/W_0 = 10^{-4}$, very large payloads could be carried.

The minimum-energy flight path to be followed by an electrically propelled spacecraft with a low thrust-to-weight ratio is shown schematically in Fig. 3. The first part of the trip would be a powered outward spiral from a satellite orbit about Earth as shown in Fig. 3(a). If the Earth-Mars transfer velocity is not reached before the gravitational field of the Sun becomes important, then all three bodies—the spacecraft, the Earth, and the Sun—must be considered in the equations of motion. Having reached the Earth-Mars transfer velocity, the spacecraft would coast outward in the gravitational field of the Sun and would meet Mars as shown in Fig. 3(b). Reverse thrust would then be applied, and the spacecraft would spiral downward into a satellite orbit about Mars. A waiting time would be required until Earth and Mars were in proper relative positions for the return trip.

The round-trip time for the Mars mission with a minimum-energy trajectory, and with $T/W_0 = 10^{-4}$, would take an electric spacecraft about 1,000 days, which is only slightly longer than the trip time required for a minimum-energy trip chemical rocket. The minimum-energy trajectory is not optimum when both trip time and payload capacity are considered. Because of the complexity of the equations of motion in gravitational fields, solutions must be obtained with digital computers; and an analytical method for trajectory optimization has not been found as yet. Moeckel[11] recently found a family of trajectories for the Mars round trip which have much faster trip times with only small reductions in payload capacity. These trajectories are indirect, as shown in Fig. 4, and require constant power, but variable thrust and variable exhaust velocity, throughout most of the flight. The thrust and the specific impulse v/g_c programing for a 500-day Mars round trip is shown in Fig. 5. The marked variation of thrust and exhaust velocity required for this mission not only illustrates the inadequacy of simplified mission analysis but also shows the wide range of operating conditions that may be required of electric propulsion systems. As Moeckel states in his paper, these trajectories are probably still not optimum so that future studies may find still faster interplanetary flight paths for electric rockets.

Power Plant and Vehicle Design

The discussion so far has emphasized that the weight of the electric power plant will have a very important effect on the payload capacity (or overall initial mass) of electric spacecraft. Because of weight considerations, it appears at present that the electric power plants of most interest for electric spacecraft are the nuclear-turboelectric and the solar-turboelectric systems. In 1957, English and associates[9, 12] made a feasibility study that included fairly detailed design estimates of a nuclear-turboelectric power plant suitable for manned space vehicles. A schematic diagram of this system is shown in Fig. 6. The study indicated that sodium would be a good heat-transfer fluid and working fluid. To protect the spacecraft crew from nuclear radiation, the heat-transfer fluid would pass from the fission reactor, through a neutron shield, through a heat exchanger, and back to the reactor. The working fluid would flow from the heat exchanger, through the gamma shield, through the evaporator, and into the turbine that would power the electric generator. To complete the thermodynamic cycle, the vapor leaving the turbine would be condensed in a radiator and returned to the heat exchanger. With a generator output power of 20,000 kw., the design study indicated that the power plant could operate at an overall efficiency of 22.7 per cent and would have a specific weight of 6 lbs./kw. The radiator weight of this system is based on an estimate of micrometeoroid penetration and will be somewhat uncertain until accurate micrometeoroid surveys are made in space.

To obtain such a low power-plant specific weight, it may be necessary to integrate the power-plant and vehicle designs, particularly with regard to the shielding and radiator configurations. A possible spacecraft design[9, 10, 12] is shown in Fig. 7. The reactor is positioned at the forward end of the 600-ft. long vehicle to reduce the nuclear radiation exposure of the crew. The neutron and gamma shields are conical to provide a shadow shielding for the rest of the spacecraft. With an eight-man crew (10 lbs./day/man for expendable supplies), 50,000 lbs. of fixed equipment, and a 40,000-lb. auxiliary rocket for landing part of the crew on Mars, the design study indicated that an output power of 11,000 kw. and an initial gross weight of about 350,000 lbs. would be required for the minimum-energy Mars round trip discussed previously. This is roughly the weight of a modern jet bomber.

Although the power-plant and vehicle designs shown in Figs. 6 and 7 are only feasibility studies, they are based on reasonable extrapolations of current technology. Needless to say, a number of problems require solution before such a spacecraft could be constructed and flown. For instance, the radiator must be as light as possible and yet sufficiently resistant to damage from micrometeoroids. Means for shielding the crew from damaging radiation (cosmic rays and solar flares) have not been included in the design study. Recent estimates[13, 14] suggest that crew shield-

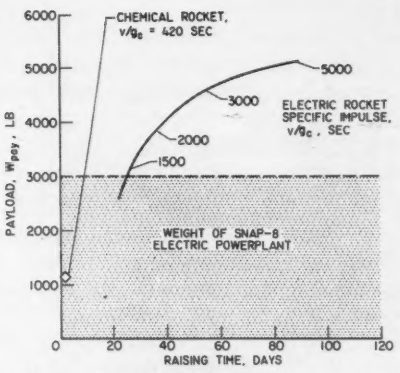

Fig. 8. Comparison of electric rocket and chemical rocket for satellite-raising mission with 60-kw., SNAP-8 power plant.[18]

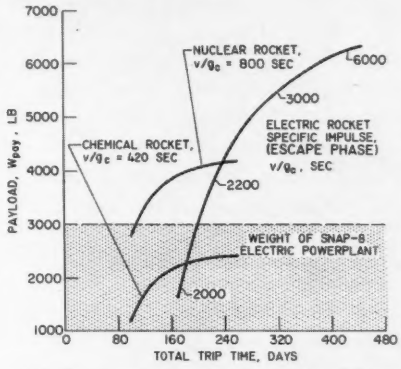

Fig. 9. Comparison of electric rocket, nuclear rocket, and chemical rocket for instrumented Mars probe mission.[18, 20]

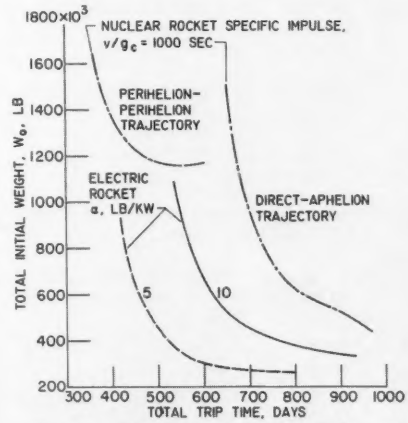

Fig. 10. Comparison of electric rocket and nuclear rocket for eight-man Mars mission. (Return payload, 50,000 lbs.[11])

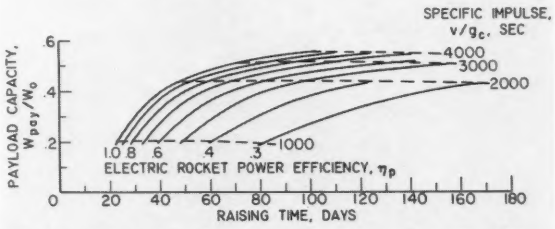

Fig. 11. Effect of electric rocket power efficiency on satellite-raising mission.

Table 1. Comparison of Electric Rocket and Chemical Rocket for Deep Space Probe Missions (After Stuhlinger[19])

Instrumented Probe To:	Chemical Rocket	Electric Rocket			
	Trip Time, yrs.	Trip Time, yrs.	Payload Weight, lbs.	Total Initial Weight, lbs.	Power Required, kw.
Jupiter	2.7	1.5	2,000	11,000	450
Saturn	6.1	2.5	2,000	11,000	450
Orbit to Pluto	45.0	3.0	2,000	11,000	2,000

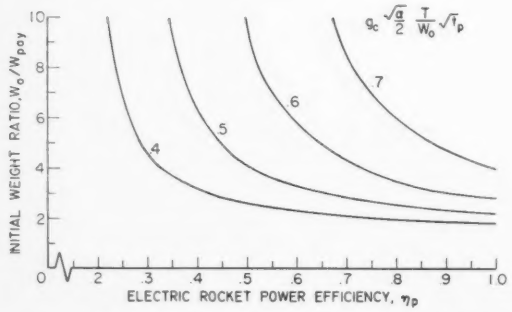

Fig. 12. Effect of electric rocket power efficiency on vehicle performance, with constant specific impulse and optimum payload.

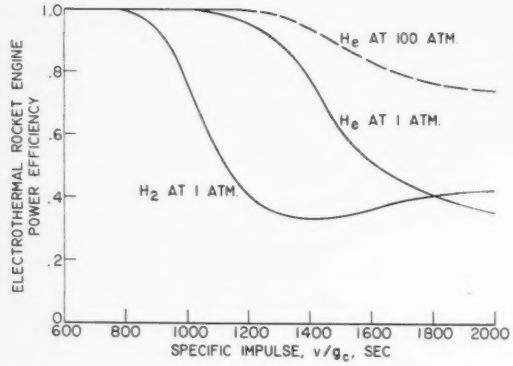

Fig. 13. Power efficiency of electrothermal rocket engines, assuming frozen flow through nozzle.[18]

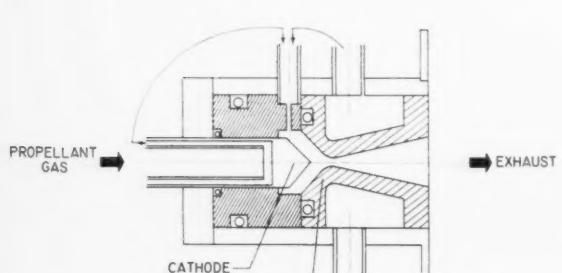

Fig. 14. Arc-jet electrothermal rocket.[25]

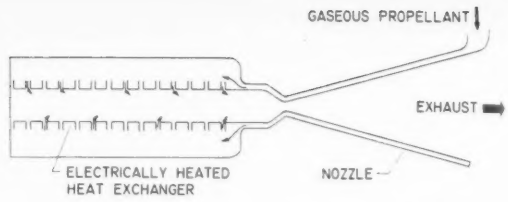

Fig. 15. Heat-exchanger electrothermal rocket.[25]

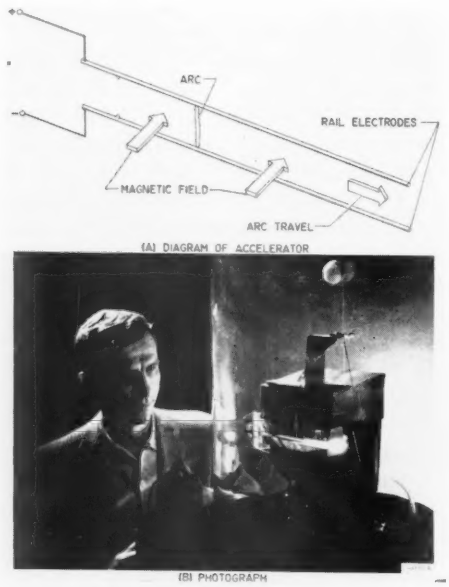

Fig. 16. Arc-rail plasma accelerator.

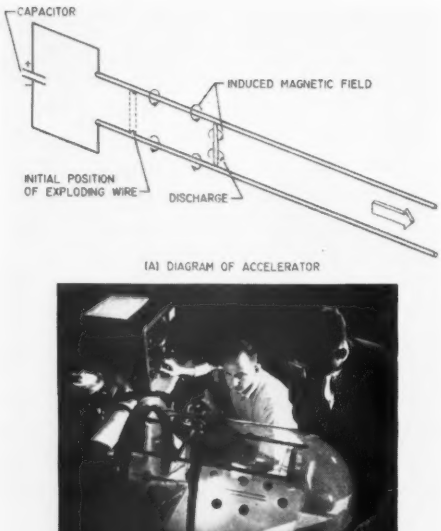

Fig. 17. Exploding-wire plasma accelerator.

ing may require quite large increases in weight, which would make the electric rocket even more attractive for manned space flight.

Solar-turboelectric power plants are also promising as a power source for electric rockets. Ehricke[15] has suggested that a large half-silvered polyester balloon might be used as a mirror to concentrate the Sun's heat onto a heat exchanger. Maslen[9] and Cooley[16] have compared the solar- and nuclear-turboelectric power systems for a variety of space missions. Based on design study estimates, and depending on the particular space mission under consideration, both systems appear promising.

The preceding discussion has concentrated on manned interplanetary missions in order to establish the long-range practicality of electric propulsion. The design studies have been intended for that purpose and do not represent definite plans at this time. As will be shown in the next section, some space missions of more immediate use may require electric propulsion systems. A nuclear turboelectric power system, the SNAP-8, which is currently under joint development by NASA and the Atomic Energy Commission, may be used in such missions.[17] This power plant will have flight capability and will have a power of 30 and 60 kw. with the latter version having a weight of about 3,000 lbs., which corresponds to a specific weight of 50 lbs./kw. Since the specific weight of nuclear-turboelectric power systems is expected to decrease with higher output powers,[9] a specific weight of 10 lbs./kw. appears reasonable for power levels in the megawatt range.

Space Missions for Electric Rockets

Electric rockets are adaptable to a number of space missions that may be classified as follows:

(1) Orientation and orbit adjustment of long-life satellites.

(2) Satellite raising.

(3) Lunar supply ferries.

(4) Mars and Venus instrumented probes.

(5) Manned interplanetary flight.

Meteorological satellites, communications satellites, and orbiting telescopes intended for long life may require orientation and orbit adjustment. If an electric power supply were a part of the payload (for communication, instrumentation, etc.), the electric rocket could use the power supply for occasional corrective thrust.

An example of a satellite-raising mission is the communications satellite that would be launched into a low orbit (say 300-mile) by a chemical rocket, and then would be raised to a 22,000-mile orbit where the orbit period is 24 hours (so that the satellite could remain over a fixed point on the equator). The performance of an electric rocket is compared with that of a chemical rocket for the satellite-raising portion of the mission[18] in Fig. 8. It is assumed here that the 60-kw., 3,000-lb. version of the SNAP-8 nuclear-turboelectric power plant would be used to power the communications equipment and that a large chemical rocket places the 9,000-lb. package into the 300-mile orbit where the satellite-raising portion of the mission begins. The 9,000-lb. package would include SNAP-8, communications equipment and propellant for raising the satellite to a higher orbit. If a small high-performance chemical rocket were to be used to raise the satellite from the 300-mile orbit to the 24-hour orbit, not even the SNAP-8 power supply could be carried when practical staging and other factors are considered. If an electric rocket (with 100 per cent efficiency) were to be powered by the SNAP-8 during the raising portion of the mission, a considerable amount of communication equipment could be carried, as shown in Fig. 8. After reaching the 24-hour orbit, the electric rocket would be turned off and used only once in a while for minor orbit adjustment, so that the SNAP-8 power plant could be used very nearly full time for communications.

When manned orbital or lunar stations become a reality, it will be necessary to supply these stations. An electrically propelled space ferry would perform such missions very well because of its large payload capacity. For instance, a 72,000-lb. ferry with a 6-megawatt power plant could carry a load of 200,000 lbs. to the Moon in 52 days and make the empty return trip in 8 days.[19]

Before manned space missions to nearby planets are made, instrumented unmanned probes may be required to observe and measure the conditions along the flight path and at the terminal planet. The electric rocket is compared with the chemical and nuclear rockets for a Mars probe mission[18, 20] in Fig. 9. In this comparison, all three rockets are assumed to

(*Continued on page 36*)

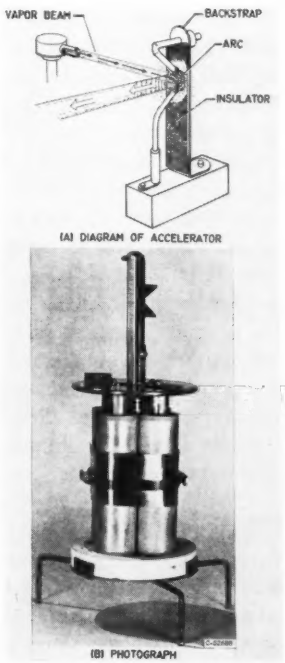

Fig. 18. Arc-backstrap plasma accelerator.

Empirical relations for the prediction of the lift and drag of unswept three-dimensional jet-flapped wings are shown, along with the necessary inputs. Plotted data show that the equations organize lift and drag data with a consistency sufficient for preliminary design use in the ranges $1 \leq C_\mu \leq 50$, $3 \leq AR \leq 10$.

Empirical Relationships for Jet-Flap Lift and Drag Prediction

D. J. Blakeslee, MIAS, *The RAND Corporation*

THE APPLICATION of blowing or suction to the trailing-edge flaps of wings has been studied for a number of years by many investigators. Such techniques increase the available lift coefficient at a given angle of attack and thus decrease landing or take-off velocities.

The maximum lift coefficient obtainable from the use of suction is that at which all flow separation is prevented and the theoretical circulation due to the flap is obtained. Flow separation on the flaps may also be prevented by blowing tangential to the trailing-edge surface of a wing-flap arrangement. To exploit these systems fully, it may be necessary to use blowing, sucking, or other devices at the leading edge to prevent separation in that region.

In the case of the blowing flap, if the amount of blowing is increased beyond that necessary to prevent separation, additional returns in augmented lift arise over the theoretical value for mechanical flaps. It is this potentiality that makes the blowing technique interesting to consider for STOL aircraft, where very high lift coefficients are required.

Lift Augmentation

The salient facts of the "additional returns" from the blowing flap are twofold: (1) The rate of increase of the lift with the blowing-rate parameter is less than that when preventing separation; and (2) the additional lift increment is composed of two parts—one part is that due to the reactive force of the jet momen-

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Symbols

AR	=	wing aspect ratio
C_D	=	total drag coefficient, Drag/$q_\infty S$
ΔC_{Df}	=	drag coefficient increment due to asymmetry or mechanical flap deflection
C_L	=	total lift coefficient, Lift/$q_\infty S$
C_{L_T}	=	lift coefficient increment due to increased circulation by the jet
ΔC_{Lf}	=	lift coefficient increment due to asymmetry or mechanical flap deflection
C_{TR}	=	thrust-recovery coefficient
C_μ	=	momentum coefficient, $wV_j/gq_\infty S$
n	=	empirical exponent
K_1, K_2	=	empirical factors
q_∞	=	free-stream dynamic pressure, lbs./ft.^{2}
S	=	wing area, ft.^{2}
V_j	=	jet velocity, ft./sec.
w	=	rate of weight flow from nozzle, lbs./sec.
α	=	angle of attack, deg.
δ	=	angle of jet sheet relative to horizontal, deg.
η	=	a form of Oswald's induced-drag efficiency factor
η_N	=	nozzle efficiency, actual thrust/theoretical thrust

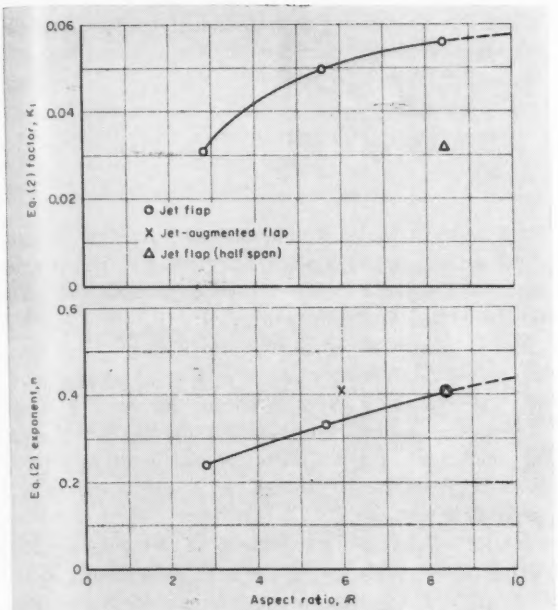


Fig. 1. Exponent and factor for Eq. (2) vs. aspect ratio.

tum; the other part is pressure lift set up over the wing by the increased circulation due to the deflected jet.

The concept here is appropriate to both jet flaps and jet-augmented flaps. That is, the wing may be designed not with a mechanical flap but so that a jet sheet issues near the trailing edge at an angle relative to the wing chord plane, perhaps with the aid of the Coanda effect; this might properly be termed a jet flap. Or one might have a wing-flap arrangement wherein the jet sheet issues near the wing-flap hinge line, following the contour of the flap. This can well be called a jet-augmented flap when the amount of blowing is more than sufficient to prevent flow separation.

Jet-Flap Data for Design

The main subject of this article is the jet flap, which achieves lift coefficients somewhat larger than those obtainable from unseparated flow over mechanical flaps (without blowing). Much work has been done in Britain, France, and the United States during the last 5 years on the theoretical and experimental performance of the jet flap, and some of this work has been reported and referenced in previous AEROSPACE ENGINEERING articles. Recently, preliminary design studies of STOL airplanes utilizing various kinds of jet flaps have been conducted.

But while quite a lot of data from tests of simple jet flaps had been accumulated, including three-dimensional tests, methods known to the author for reducing the drag data did not accommodate large amounts of data and did not result in uniformity, and no theoretical analysis for large jet stream angles had been devised to satisfy the need for predicting the drag at different flap angles and momentum coefficients. During the course of work at RAND, however, a measure of success in such a drag correlation has been obtained. The results shown here are limited in that they represent help in only a small part of the overall design problem for jet-flapped aircraft, but sufficient interest has been expressed to make it worth while to publish them for general use. This represents the basis on which the effects of ground proximity, sweep, and trim may be added for the preliminary design.

Jet-Flap Circulation Lift

The lift coefficient due to the added circulation is easily obtained in a consistent manner from experimental data. This lift is also analyzed in this paper, mostly for the sake of completeness, from the same NASA data[1-4] used later for the less obvious drag delineation. The total lift coefficient of a jet flap or jet-augmented flap is here expressed as

$$C_L = C_L(\delta = 0) + \Delta C_{L_f} + C_{L_\Gamma} + \eta_N C_\mu \sin(\delta + \alpha) \quad (1)$$

The notation follows NASA convention, for the most part. The momentum coefficient C_μ is calculated using mass flow through the slot and theoretical velocity for isentropic flow. The nozzle efficiency η_N is used to convert the last term to the actual thrust reaction in the vertical direction, rather than the theoretical, and was calculated from the test data at zero jet deflection. This is not intrinsically justifiable, in view of unknown losses due to turning, for example. However, this device describes the situation realistically, and it did succeed in bringing the drag information into a more consistent pattern. The information presented here is for $\alpha = 0$ deg. This paper does not purport to show an angle-of-attack effect, although the maximum C_L does not occur, in general, at 0 deg. The NASA data show the slope of C_L vs. α to be roughly the same for the range of about $1 \leq C_\mu \leq 10$. But the curves show too many variations to afford generalization of the angle-of-attack effect; preliminary design studies at this point usually use 0-deg. values for these reasons and also because this is a practical take-off and landing attitude.

Approximate two-dimensional flap analogy theories[5, 6] for the lift of a jet flap show that the lift coefficient of a jet flap varies almost according to $C_\mu^{1/2}$ and δ. The NASA data used gave rise to

$$C_{L_\Gamma} = K_1 \delta C_\mu^n \quad (2)$$

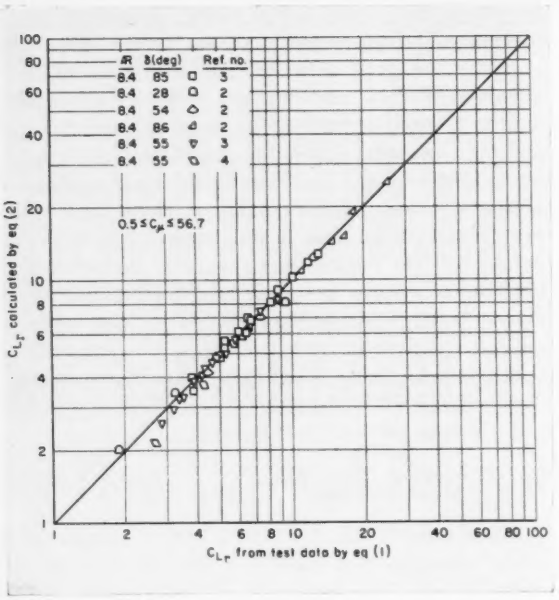


Fig. 2a. Representation of test data by Eqs. (1) and (2).

In Fig. 1, where K_1 and n are plotted, it can be seen that the exponent does indeed become as great as 0.4 at an aspect ratio greater than 8. Values of K_1 and n from a single comparable jet-augmented flap test program[2] are included for comparison. For this, the wing area includes the mechanical flap area. Also the result from data of a single comparable semi-span (inboard) nozzle jet flap[4] is shown. The points at aspect ratios 2.8 and 5.6 represent a smaller amount of test data and are thus less well supported than those at 8.4.

Figs. 2a and 2b are included to show how faithfully the test data are represented by Eqs. (1) and (2), and to show the amount of thoroughness with which the test model geometries cover the spectrum of interest.

Jet-Flap Thrust Recovery

Theoretical and experimental information leads one to expect an induced thrust, or thrust recovery, which is to say that the horizontal thrust at forward velocity is greater than that due to the horizontal component of the jet reaction alone. The catch-all wing efficiency factor in the induced-drag term will include any thrust recovery if nothing further is done to the usual drag equation other than the addition of a jet-reaction term. Or, the thrust-reaction term might be altered to account for some recovery. Both of these approaches have been tried, but to the author's knowledge they have not been shown to correlate simply a large amount of data over a range of geometries and C_μ. The empirical method shown in this paper, however, does fit the information from which it was derived with sufficient fidelity for most preliminary design purposes, and the test data used are rather diverse in geometry and C_μ.

The total drag coefficient may be expressed as

$$C_D = C_D(\delta = 0) + \Delta C_{D_f} - \eta_N C_\mu \cos(\delta + \alpha) + (C_{L\Gamma}{}^2/\eta\pi_\epsilon R) - C_{TR} \quad (3)$$

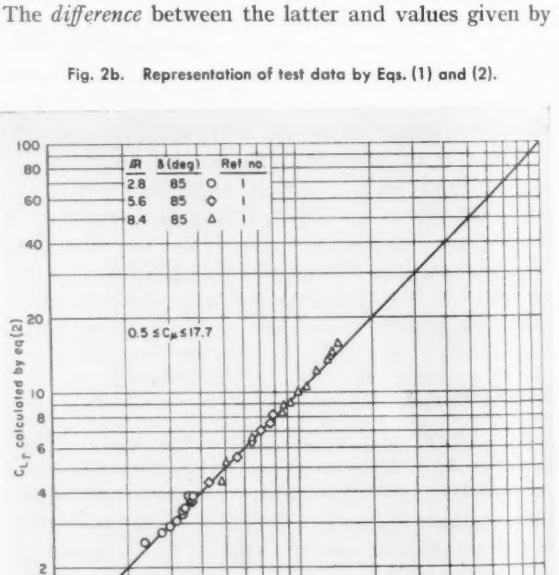
This appears to be a coherent and realistic way to express the drag of a jet-flapped wing in the present state of knowledge. The reaction term is meant to be the actual reaction component, the wing has the same "aspect-ratio efficiency" (expressed by η) when the jet flap is blowing as when it is not, and any bonus in thrust recovery experienced by the wing is meant to show up separately in C_{TR}. As in the equation for lift coefficient, Eq. (3) is conceptually correct for α different from zero, although it is supported in this paper only at $\alpha = 0$.

And this device does succeed in bringing about a pattern of consistency in the test data used. When Eqs. (1) and (3) were used to break down the data, C_{TR} corresponded fairly well to

$$C_{TR} = K_2 \delta^{1.23} C_\mu \quad (4)$$

Some credence for this is given by the following. The two-dimensional theory of reference 7 (valid for small δ) shows that jet-flap thrust varies according to C_μ and as a trigonometric function of δ. Notably, however, C_{TR} represents a "bonus" in thrust over that given by the horizontal component of the jet reaction. The *difference* between the latter and values given by

Fig. 2b. Representation of test data by Eqs. (1) and (2).



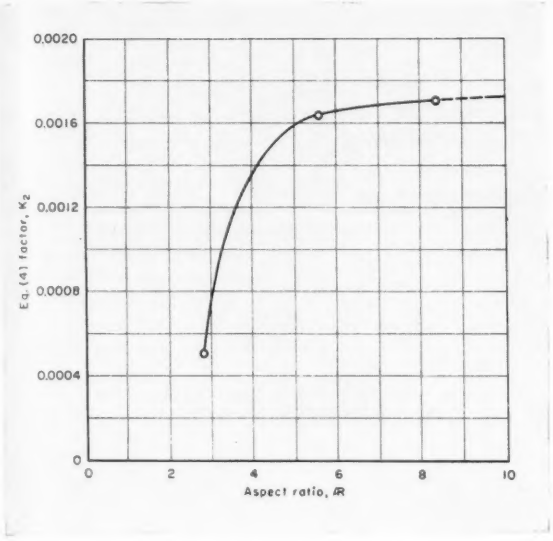


Fig. 3. Factor for Eq. (4) vs. aspect ratio.

the theory of reference 7 for appropriate angles and by two-dimensional test values at greater angles can be well represented as proportional to $\delta^{1.23}$.

The term K_2 is a function of aspect ratio and is plotted in Fig. 3. Fig. 4 is included to show the scatter in the comparison of C_{TR} calculated by means of Eq. (4) with C_{TR} from the test data themselves. This drag delineation clearly does not result in so faithful a representation of the data as did the method for lift and should not be used at all for values of C_μ less than about 1.0. The fact that the exponent is given as 1.23 rather than 1.20 or 1.25 must not be construed as implying precision. It is just the best representation for the data with this simple equation. As was the case with $C_{L\Gamma}$, the aspect-ratio variation is better supported by data near AR = 8.4 than at lower values.

The data from the single applicable jet-augmented-flap test were too limited to be used with confidence for this purpose. The three usable points gave about the same or slightly less thrust recovery than the plain jet flap. The single set of half-span data was quite inconsistent when analyzed according to Eq. (4), with C_{TR} values ranging between ± 0.05 in the C_μ range available ($C_\mu \leq 3.6$).

Further speculation on the validity of Eqs. (3) and (4) will not be made here. More sensitive drag measurements would be necessary to substantiate the more detailed analyses that might alter or replace the present method.

Conclusions

A rather large agglomeration of test points from NASA tests of the lift and drag of jet-flapped wings is represented by empirical relations with a fidelity shown graphically. The principal innovation is that a thrust-recovery coefficient can be subtracted from the drag-coefficient equation to represent the so-called thrust recovery or induced thrust of jet flaps. This thrust-recovery coefficient is simply related to jet-flap parameters. It is directly proportional to the momentum coefficient and varies approximately as a simple power of the flap angle.

References

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[2] Lockwood, V. E., Turner, T. R., and Riebe, J. M., *Wind-Tunnel Investigation of Jet-Augmented Flaps on a Rectangular Wing to High Momentum Coefficients*, NACA TN 3865, Dec., 1956.

[3] Vogler, R. D., and Turner, T. R., *Wind-Tunnel Investigation at Low Speeds to Determine Flow-Field Characteristics and Ground Influence on a Model with Jet-Augmented Flaps*, NACA TN 4116, Sept., 1957.

[4] Gainer, T. G., *Low-Speed Wind-Tunnel Investigation to Determine the Aerodynamic Characteristics of a Rectangular Wing Equipped With a Full-Span and an Inboard Half-Span Jet-Augmented Flap Deflected 55°*, NASA Memo 1-27-59L, Feb., 1959.

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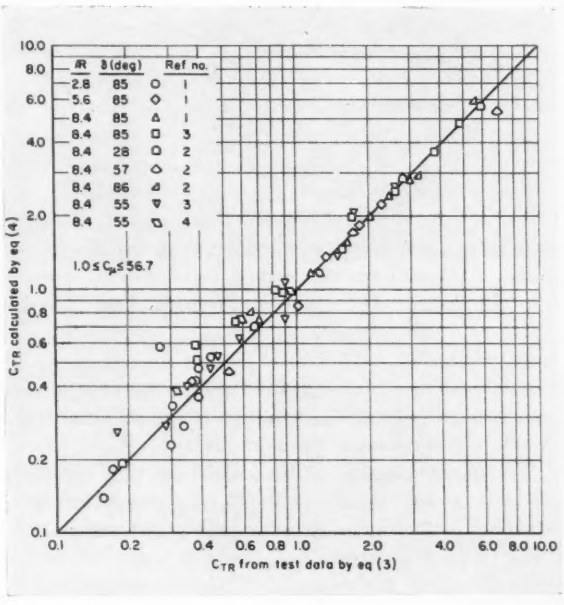
[6] Jacobs, W. F., and Paterson, J. H., *The Jet-Flapped Wing in Two- and Three-Dimensional Flow*, IAS Preprint No. 791, Jan., 1958.

[7] Yen, K. T., *On the Thrust Hypothesis for the Jet Flap Including Mixing Effects*, Rensselaer Polytechnic Institute, TR AE 5902, June, 1959.

Fig. 4. Representation of test data by Eqs. (3) and (4).



A simple and consequently inexpensive method of testing jet engines and calibrating flight-test instrumentation at simulated flight conditions is presented here. The method was developed and used at the Convair-Fort Worth Ground Test Stand during the B-58 program. Results proved the method to be a useful tool in determining in-flight thrust and analyzing various engine performance parameters.

Simulated Flight Testing

of a Cowled Turbojet Engine by Use of an Exhaust Ejector

J. C. Armstrong, R. W. Flados, and W. T. McKenzie, MIAS

Convair-Fort Worth, A Division of General Dynamics Corporation

ONE OF THE most difficult problems in jet aircraft flight-test evaluation is to separate engine and aircraft effects. It is possible to know quite accurately the performance of the aircraft-engine combination and still not know which part is contributed by aircraft drag and which part by engine thrust. However, to evaluate changes and know which areas require the most emphasis, it is necessary to determine individual effects. One key to this is accurate determination of in-flight thrust. To obtain in-flight power-plant performance, extensive instrumentation is required. Since much of the instrumentation is affected by the airframe installation, it is desirable to calibrate the instrumentation in the environment of a production installation. This was accomplished for the Convair B-58 by using a production inboard nacelle with a bellmouth in front of the inlet lip mounted in a ground test stand and lowering the nozzle exit pressure by use of an ejector-type exhauster.

The system was designed to utilize the energy from the exhaust jet and thus simulate altitude and flight Mach number (engine pressure ratio).

To simulate engine cruise conditions, it is necessary to create a ram pressure ratio (P_{t_2}/p_{10}) across the engine identical to that experienced in flight. By reducing p_{10} (the pressure surrounding the convergent-divergent exhaust nozzle) by means of an ejector system and by maintaining nearly ambient pressure at the compressor face, an effective flight Mach number was simulated.

Mr. Armstrong (*left*) received his B.S. degree in physics from the University of Kentucky in 1943 and at that time joined the Lewis Lab. of NACA. His work at NACA involved turbojet engine performance evaluation in altitude test chambers, especially in the field of high-altitude engine starts. He moved to Convair-Fort Worth in 1956 as a Senior Propulsion Engineer in the Aerospace Sciences Section of the Engineering Department where he has been engaged with ground and flight testing and evaluation of the B-58 power plant and inlet.

Mr. Flados (*center*) received his B.S. degree in aeronautical engineering from the Georgia School of Technology in 1947. He also has done graduate study at Southern Methodist University. Since 1947 he has been employed at Convair-Fort Worth as a Performance Engineer and as a technical representative to SAC on B-36 cruise control and engine operation, and is presently Propulsion Ground and Flight Test Coordinator on the B-58. He has been actively involved in early boost-glide flight path optimization for air-launched missiles, high-altitude testing of the B-36, thrust-drag determination of the B-36 and B-58, and testing of the General Electric J-79 engine. Mr. Flados has been particularly interested in private aviation, having been a pilot, aircraft owner, designer, and builder.

Mr. McKenzie (*right*) is a Senior Propulsion Engineer in the Aerospace Sciences Section of the Engineering Department at Convair-Fort Worth. He received his B.S. degree in mechanical engineering with aeronautical option from the University of Oklahoma in 1951, and has been employed at Convair since that time; he also has done graduate work at Southern Methodist University. Mr. McKenzie has been interested in internal aerodynamics design and testing of the B-58 power plant, specializing in exhaust nozzle and ejector design. He is a private pilot and a member of the IAS.

Symbols

A_8	= primary nozzle area
N	= engine r.p.m.
θ	= $T_{t_2}/5{,}186°\text{R}$.
T_{t_8}	= primary nozzle air total temperature
P_{t_2}	= compressor face total pressure
(p_{10})	= static pressure in nozzle plenum chamber
(p_o)	= atmospheric pressure in test cell
W_1	= primary nozzle airflow
W_2	= secondary airflow
A_1	= engine inlet area just aft of A_{1a}
p_1	= static pressure at A_1
m_1	= air mass flow at A_1
V_1	= air velocity at A_1
A_m	= maximum cross-sectional area of nacelle
A_{1a}	= area of engine inlet just aft of bellmouth rubber scale
p_{1a}	= static pressure on aft side of bellmouth rubber seal
A_9	= secondary nozzle exhaust area
p_9	= static pressure at A_9
m_9	= air mass flow at A_9
V_9	= air velocity at A_9
A_{10}	= inside cross-sectional area of nozzle plenum chamber
F_{inlet}	= rearward forces on engine-nacelle
$F_{exhaust}$	= forward forces on engine-nacelle
F_{scale}	= resultant force on engine-nacelle ($F_{exhaust} - F_{inlet}$)
F_g	= gross thrust

With ambient pressure at the inlet (P_{t_2}) and a simulated flight Mach number of 0.92, the simulated altitude was about 15,000 ft.

The test inlet total temperatures were lower than standard-day, 15,000-ft., in-flight total temperatures. However, this can be corrected for by operating the engine at the correct $N/\sqrt{\theta}$ to simulate the desired flight condition.

Proper secondary airflows and pressures were obtained between the engine and nacelle because of secondary nozzle pumping and sealing nacelle leaks.

Facility

Inlet

The nacelle inlet bellmouth design of Fig. 2 was dictated by the following requirements:

(1) Measure absolute inlet airflow within ±1 per cent.

(2) Maintain engine inlet total pressure distribution similar to that at flight cruise conditions.

(3) Provide a frictionless seal between bellmouth duct and production cowl lip.

The bellmouth contour is a quarter ellipse with the minor axis of the ellipse two thirds of the major axis. A 10-in.-long cylinder is attached between the bell section and the inlet to provide a parallel flow section for measuring airflow. The low losses inherent in a bellmouth enable the air to approach the nacelle inlet with parallel flow and a uniform total pressure profile similar to the inlet conditions during subsonic cruise.

To ensure accurate thrust measurements, it was desirable to isolate the bellmouth from the nacelle. This was accomplished by mounting it on a ground-supported framework and connecting the adapter duct to the cowl lip through a frictionless rubber diaphragm-type seal (Fig. 1). The seal imposed only aerodynamic forces on the nacelle which can be determined using test pressure data.

Exhauster

The design of the exhauster was accomplished with the aid of reference 2. By selecting the flow conditions covering the subsonic cruise regime for the Convair B-58 and introducing the known engine parameters such as exhaust nozzle area, mass flow, tailpipe pressure and temperature, it was possible to determine the best full-scale ejector dimensions. A schematic of the ejector exhauster system is presented in Fig. 2.

A mixing tube 30 in. in diameter and 180 in. long was mounted 10 in. downstream of the engine exhaust nozzle. Attached to the mixing tube exit was a diffuser 100 in. long with an exit to inlet area ratio of 2.0. The diffuser and mixing tube are shown schematically in Fig. 2. (*Continued on page 52*)

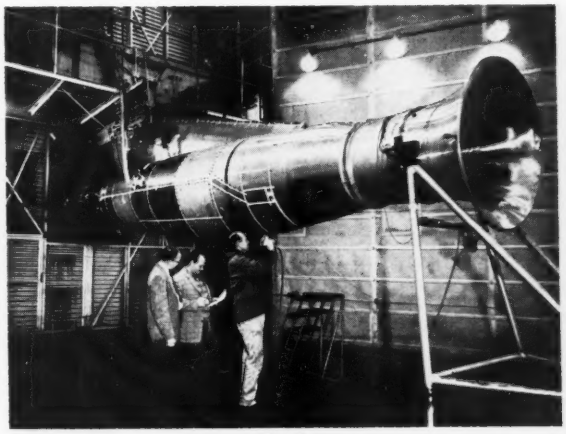


Fig. 1.

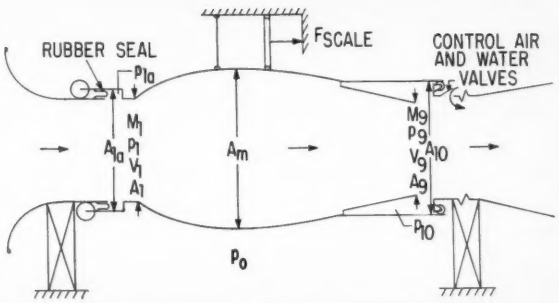


Fig. 2. Schematic diagram for force evaluation.

Performance and Design Considerations for Maneuvering Space Vehicles

L. W. Warzecha, AFIAS, *General Electric Company*

SPACE VEHICLE and satellite flights to date have been completely ballistic, with no significant maneuvers being performed after final stage burnout. Since the major fundamental problems of ballistic orbital flight are solved or near solution, increasing interest and attention are now directed toward the prospect of maneuvering space vehicle flight. Many excellent papers and studies have been presented on the subject of orbital rendezvous and guidance, control, propulsion, and instrumentation required for rendezvous. This paper presents the results of a number of design and performance studies of maneuvering space vehicles. In particular, many numerical results are presented, providing an insight into the sizing and magnitude proportions for vehicles to perform the missions discussed.

Mr. Warzecha is Manager of Advance Space Vehicle Engineering with G-E's Missile and Space Vehicle Department. A 1948 graduate in Electrical Engineering from the University of Texas, he joined G-E's Engineering Training Program. After completing the program, he was appointed Supervisor of the Advanced Technical Course with responsibility for establishing, developing, and operating a broad educational training course directed toward creative and analytical design. Since joining MSVD in 1955, Mr. Warzecha has participated in system development, systems synthesis and configuration studies, and systems design integration for the Atlas and Thor re-entry vehicle programs. He has been a Project Manager on Able Phase I and a Technical Group Leader of Systems Engineering for ballistic missile systems. He was named to his present position in 1959.

Space Maneuvers

As considered here, a *space maneuver* is one occurring outside the earth's atmosphere, or one in which the primary function is to establish a desired flight path for conduct of an operation outside the earth's atmosphere.

Space Maneuver Requirements

In analyzing the performance of space maneuvers for initial studies, the parameter of prime importance is the required characteristic velocity increment. The characteristic velocity determines the requirements and design of the maneuver stage propulsion system and gross sizing of the vehicle. The characteristic velocity is influenced to some extent by the guidance and control concept and the equipment mechanization employed, but this variation is relatively unimportant to the current study. Throughout, an efficient guidance and control system is assumed. It is further assumed that reasonable time periods are available for accomplishment of maneuvers so that gross inefficiencies do not result.

Many missions requiring space maneuvers have been suggested and discussed. The most important and earliest of such missions are listed in Table 1, along with significant factors and the required characteristic velocity increments.

Satellite inspection missions will be required for surveillance, inspection, investigation, and analysis of unknown space vehicles or satellites. Retrieval and rescue vehicles will be required for return to earth of vehicles from space. Enemy vehicles may be captured and returned, and valuable payloads, including man, may be rescued as necessary. Space ferry missions, of course, will ferry men and material to space stations and return. These missions are all similar in that they require rendezvous maneuvers, will probably be initiated at near-orbital velocities, and will consist of a single rendezvous operation per flight. It is seen, from the required characteristic velocity increments, that these missions must be performed from coplanar trajectories or from angles of 10° or less between trajectory planes. The number of operations per flight must be limited to a minimum, especially since additional operations usually will require operations with less favorable initial conditions of relative position and

An analysis is made of the required degree of maneuverability for a variety of space missions, including return to the earth's surface. Design and performance penalties associated with high degrees of maneuverability are presented, with particular attention directed toward near-earth orbital flight. Principal conclusions are as follows:

(1) *Space maneuvers—Initial space maneuvers will be limited by propulsion requirements and will consist of simple rendevous and intercept in near-earth orbital flight.*

(2) *Orbital return maneuvers—Vehicle landing or recovery maneuvers will be required for landing at a preselected site from a low-altitude orbit on any chosen day, even though that site may be substantially far away from the satellite orbital plane. In most practical cases, recovery maneuvers will be performed more economically by semi-ballistic aerodynamic glide than by rocket-powered flight.*

(3) *Vehicles—A modular system for payload and mission flexibility can be achieved without significant weight or performance penalties.*

trajectory plane inclination. Even so, velocity requirements of about 5,000 ft./sec. will be common for single-rendezvous maneuvers.

Space search and reconnaissance and patrol missions may require rendezvous capability, or, in some cases, simply intercept maneuvers. It is highly likely that large trajectory plane changes will be required, perhaps up to 45 deg. or more. Multiple operations per flight, up to 10 or more, will be highly desirable. The velocity requirements for these missions are seen to be as high as 200,000 ft./sec., with a probable minimum of 5,000 ft./sec. It is concluded that these missions must await major propulsion developments.

Satellite kill missions will require primarily intercept maneuvers, with a single operation per flight, and small trajectory plane changes in the terminal stage. Characteristic velocity increments will be 5,000 ft./sec. or less. An early capability for this mission is evident.

Characteristic Velocity Requirements

Studies have been made of the effect of initial conditions on the characteristic velocity requirements for rendezvous. Variations in initial relative range from the rendezvous vehicle to the space vehicle, initial velocity decrement of rendezvous vehicle from the space vehicle, and trajectory planar angle are considered. In all cases, an orbital altitude of 200 n.m. is used, the rendezvous vehicle is at apogee of a ballistic flight at initiation of the rendezvous, and the rendezvous vehicle leads the space vehicle. Initial velocity decrements of 1,000 to 5,000 ft./sec. are considered. The initial relative range is from 10 to 50 n.m., and the initial trajectory planar angle is 30° or less. Numerical results are presented in Fig. 1. It is seen that, as the initial planar angle increases to 30°, the effects of initial velocity decrement and relative range essentially vanish. Under no condition was initial relative range a highly significant parameter.

Space Maneuver Stage Weight

Maneuver stage sizing studies have been made for a number of combinations of initial conditions and maneuver requirements. Typical results are presented in Fig. 2 and 3. The weight of the space maneuver stage (not including useful terminal stage weight) is shown for characteristic velocity increments of 1,000 to 6,000 ft./sec. For Fig. 2, the engine specific impulse is 300 sec., and for Fig. 3, it is 400 sec. In each case fuel weight is 80 per cent of the total weight of the space maneuver stage. The obvious benefit of higher specific impulses is evident.

For a typical case of rendezvous with a 5° plane

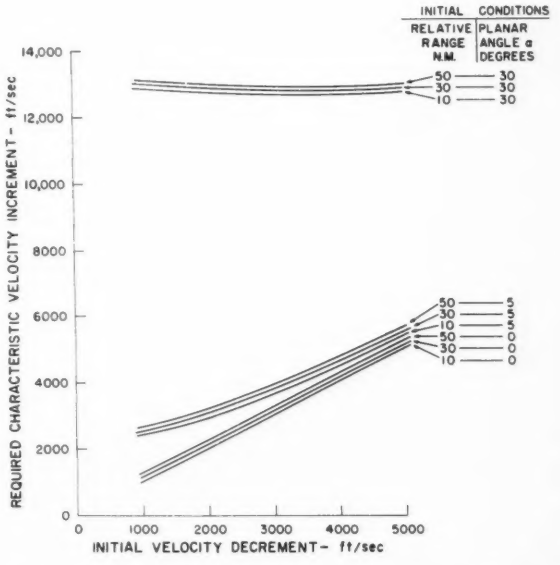


Fig. 1. Required characteristic velocity increment for orbital rendezvous maneuvers at 200 n.m. orbital altitude.

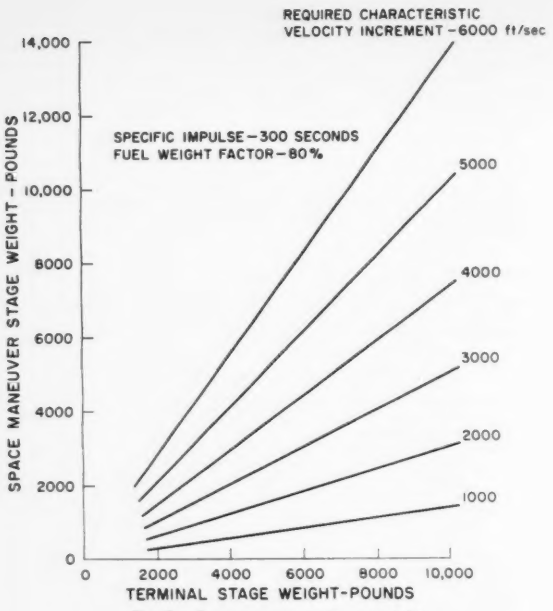


Fig. 2. Space maneuver stage weight.

change and an initial relative range of 50 n.m., the required space maneuver stage weight is presented in Fig. 4. For an initial velocity decrement of 5,000 ft./sec., as was seen in Table 1 as typical for a *retrieval mission*, the space maneuver stage would weigh about 7,500 lbs. in order to maneuver a terminal stage weighing 6,000 lbs.

In general, it is seen that space maneuver stage weights appear quite reasonable for simple, highly constrained, rendezvous missions. Consequently, it is evident that space maneuver flights will be limited to such less-demanding mission requirements for some time, and, indeed, such flight programs are technically ready for implementation at an early date.

Orbital Return Maneuvers

Maneuvers in orbital return flights have been of interest primarily to provide a higher degree of control over return trajectory and landing area than is possible by purely ballistic flight. Experience to date has shown some difficulty in making precise preflight determination of the orbital parameters to be achieved in flight. Thus, in addition to the problem of high dispersion in returning on a shallow re-entry trajectory, there is relatively little control of landing point, to the extent that landing must occur within the orbital plane for a nonmaneuvering vehicle.

The benefits of cross-range maneuver capability during orbital return have been studied extensively. Fig. 5 shows typical—and significant—results. Polar orbits are considered, with landing or recovery areas in the vicinity of 40° North Latitude. Circular orbits at altitudes of 100, 500, and 1,000 n.m. are shown. The number of days per month on which return to a preselected, fixed landing location can occur is shown as a function of cross-range maneuver capability. For polar orbits, the curve shows the number of days per month at which landing can occur on a North-to-South pass. An equal number of opportunities exists on South-to-North passes. It is seen that to make an assured daytime recovery landing at a preselected site on any chosen day of the month from an orbit at 500 n.m. altitude requires a cross-range maneuver capability of somewhat under 600 n.m. in either direction from the orbital flight plane. Aerodynamic glide and oriented rocket impulse techniques are evaluated as means of providing this cross-range maneuver capability.

Aerodynamic Glide Maneuver

One method of attaining the cross-range maneuver is by initiating an equilibrium glide early in re-entry along a very shallow flight path and banking the vehicle to obtain the desired range/cross-range relationship. The capability of such an approach is shown in Fig. 6 as a function of aerodynamic lift-to-drag ratio. In this case, for maximum cross-range maneuver, the glide is initiated at nearly (99 per cent) orbital velocity and the vehicle is banked to approximately 30° for maximum cross-range correction. In operating at the maximum cross-range capability, necessarily the downrange trajectory flexibility has been severely restricted, and adjustments must be made in the time and position at which retrorocket firing and orbit ejection occur. It is seen from Fig. 6 that a cross-range correction capability of 600 n.m. in either direction from the orbital plane requires a lift-to-drag ratio of approximately 1.3; 1,100 n.m. requires L/D of 2.

A number of preliminary design and analysis studies of aerodynamic glide vehicles have shown payload weight fractions (Fig. 7). Payload weight and L/D are parameters determining the payload weight fraction, or payload carrying efficiency, of the vehicle design.

Oriented Rocket Maneuver

The effectiveness of providing the required cross-range maneuver by properly orienting a rocket propulsion impulse at orbit ejection has been considered. The effectiveness of this technique is illustrated in Fig. 8, which shows the required maneuver propulsion weight, for a range of cross-range capabilities and for selected combinations of propellant specific impulse and maneuver stage fuel weight factor. As an example, for a cross-range maneuver of 500 n.m., with specific impulse of 300 sec. and fuel weight factor of 80 per cent, the required propulsion weight is 55 per cent of the weight of the basic vehicle being maneuvered.

Comparison of Aerodynamic and Rocket Maneuvers

Studies have been made to compare, on a weight basis, the effectiveness of the aerodynamic and rocket maneuver systems for cross-range corrections. In these studies, note has been made of the fact that the rocket maneuver vehicle will require some aerodynamic lift and guidance and control for final control of flight path, inasmuch as the proposed rocket correction

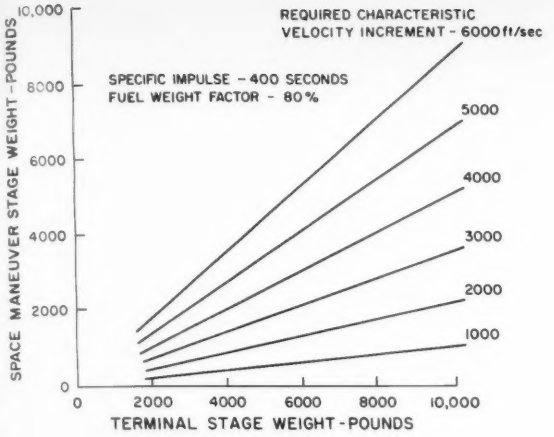


Fig. 3. Space maneuver stage weight.

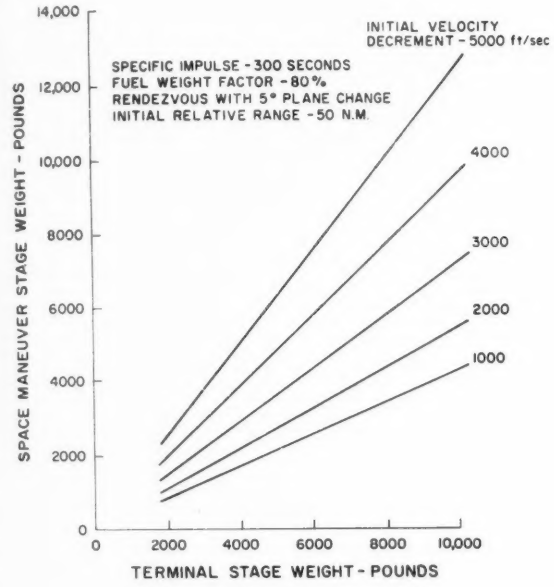


Fig. 4. Space maneuver stage weight.

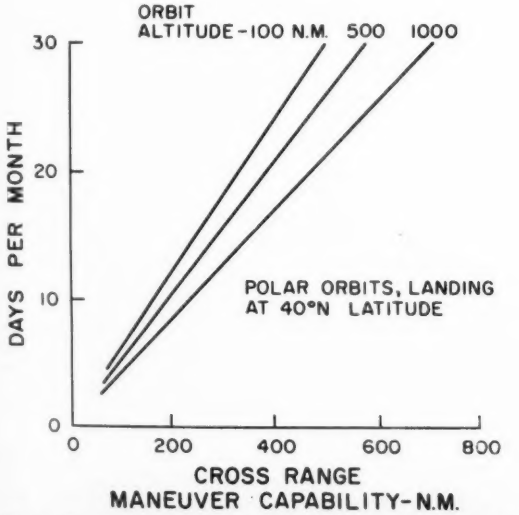


Fig. 5. Days per month available for landing at preselected point.

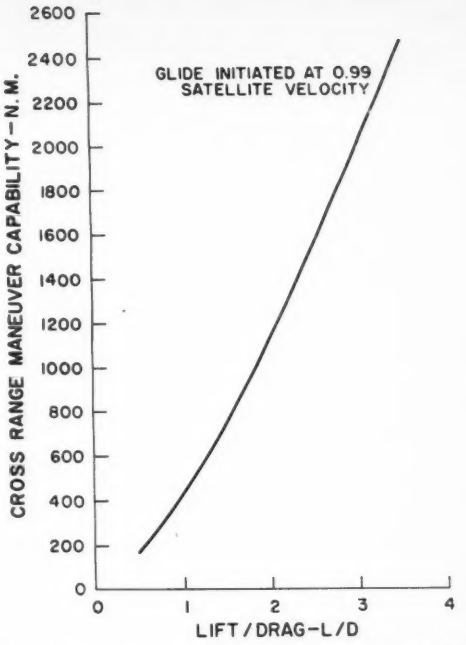


Fig. 6. Cross-range maneuver capability by aerodynamic glide.

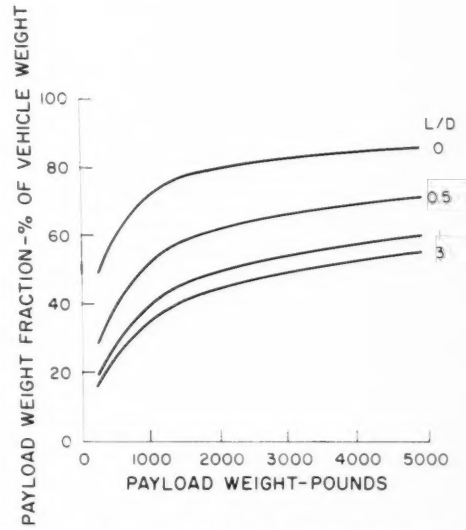


Fig. 7. Payload weight fraction for aerodynamic glide vehicles.

Table 1. Space Maneuver Requirements

MISSION	TYPE OF MANEUVER	ANGLE BETWEEN TRAJECTORY PLANES	INITIAL VELOCITY	NUMBER OF OPERATIONS PER FLIGHT	REQUIRED CHARACTERISTIC VELOCITY INCREMENT
SATELLITE INSPECTION RETRIEVAL / RESCUE FERRY	RENDEZVOUS	0°	NEAR ORBITAL	1	0-1000 fps
		5-10°	NEAR ORBITAL	1	2000-5000 fps
		20-30°	NEAR ORBITAL	1	10,000-15,000 fps
		20-30°	NEAR ORBITAL	5	50,000-75,000 fps
SPACE SEARCH RECONNAISANCE / PATROL	INTERCEPT RENDEZVOUS	15-45°	ORBITAL	1	5000-20,000 fps
		15-45°	ORBITAL	10	50,000-200,000 fps
SATELLITE KILL	INTERCEPT	0-5°	APOGEE BALLISTIC COAST	1	0-5000 fps

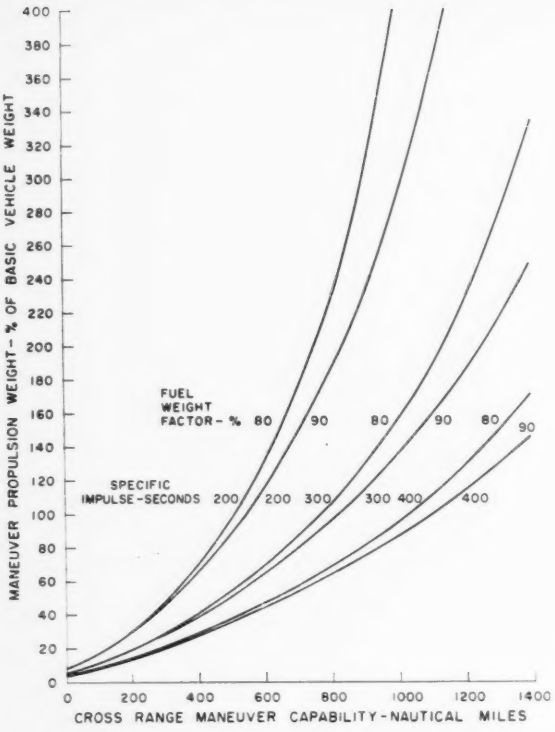


Fig. 8. Cross-range maneuver capability by rocket propulsion.

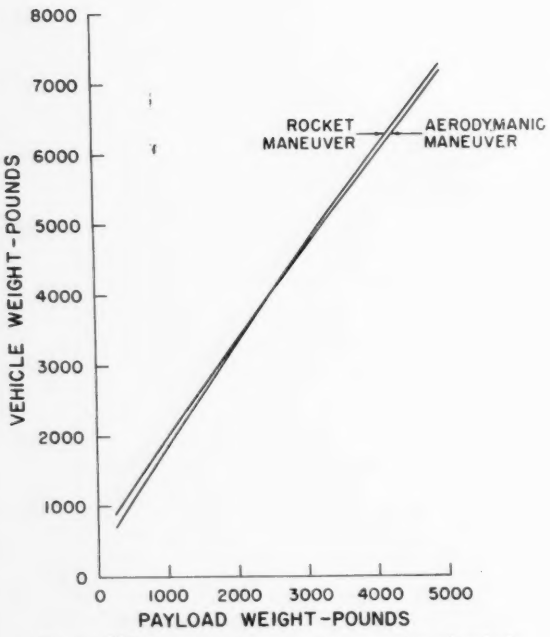


Fig. 9. 200 n.m. cross-range correction, comparison of methods.

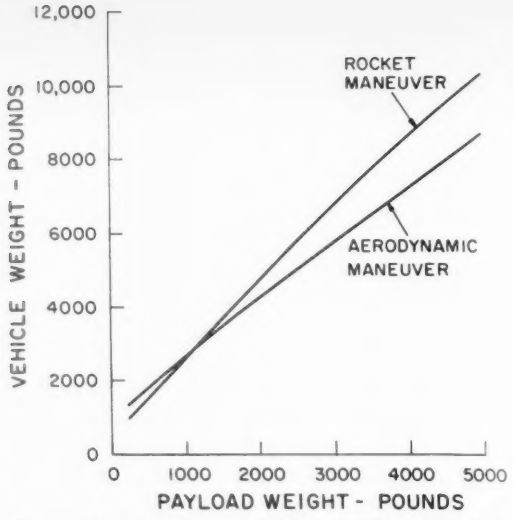


Fig. 10. 600 n.m. cross-range correction, comparison of methods.

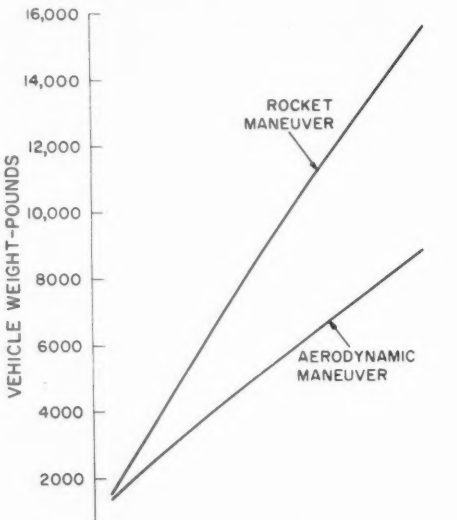


Fig. 11. 1,000 n.m. cross-range correction, comparison of methods.

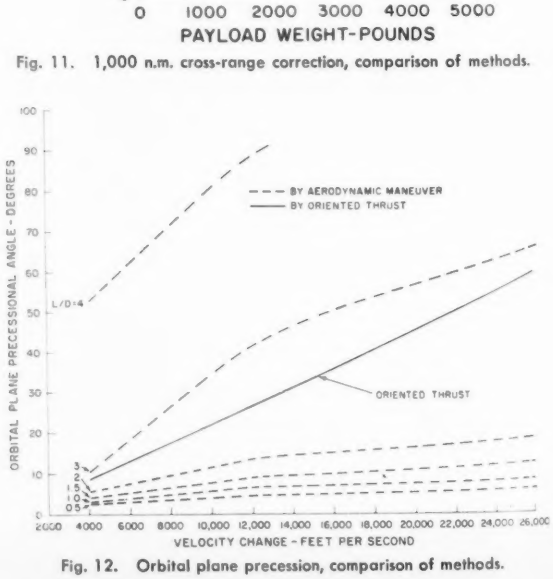


Fig. 12. Orbital plane precession, comparison of methods.

would be made before re-entry and trajectory errors would result in substantial dispersions at landing conditions. Typical results are shown by Figs. 9,10, and 11, respectively, for cross-range maneuvers of 200, 600, and 1,000 n.m. For these curves, the rocket system is based on a specific impulse of 300 sec. and a fuel weight factor for 80 per cent, both of which are probably optimistic values for early flight systems. It is seen that for small corrections, there is little choice between the two methods, whereas a distinct weight advantage is seen for the *aerodynamic maneuver* for larger maneuver requirements and heavier payloads.

Orbital Plane Precession

A special maneuver problem of some interest is the problem of orbital plane precession, particularly in the case of *satellite kill* or *inspection/retrieval/rescue*, where the nature of the orbit of the subject vehicle and the location of available launch sites may require significant plane changes. Brief consideration has been given to the concept of placing the satellite kill vehicle in a low-altitude orbit and aerodynamically maneuvering it into the desired orbital plane. In this maneuver, of course, kinetic energy will be lost, and the vehicle must be reaccelerated to orbital velocity. Fig. 12 shows the aerodynamic precessional capability as a function of L/D and velocity loss, with oriented thrust shown for comparison. It is seen that aerodynamic vehicular L/D of approximately 3 is required for a favorable comparison with oriented thrust propulsion techniques for this purpose.

Orbital Return Vehicle

A specific vehicle of some interest for orbital return has been studied in some detail. The major concepts and requirements of this vehicle are given in Table 2. A capability for call-down and landing at a preselected, fixed location on any chosen day, from low-altitude orbits, requires a cross-range maneuver capability of 550 n.m. Aerodynamic cross-range maneuver is selected for maneuver efficiency and flexibility. The vehicle is terminally guided from orbit ejection to recovery and landing operations. A parachute recovery system is chosen instead of conventional landing systems to permit use of a low lift design and to provide early hardware capability. Glide will be initiated at near-orbital velocity. The orbital return flight profile is selected for near-minimum lift-to-drag ratio. For this particular case, a payload of 2,000 lbs. has been studied, and flexibility for varied payloads and mission requirements was essential.

Table 2. Vehicle Concept

Call-down of any chosen day
550 n.m. cross-range maneuver
Aerodynamic cross-range maneuver
Terminal guidance from orbit to landing/recovery
Parachute recovery
Glide initiated at near-orbital velocity
Flight profile selected for minimum L/D
2000-lb. payload
Payload/mission flexibility

A typical vehicle configuration for the *orbital return vehicle* (ORV) is shown in Fig. 13. Aerodynamically the vehicle is essentially a half sphere-cone, with control wedges for trim at the required angle of attack and for roll control through differential trim. The approximate weight breakdown for ORV is given here, with a total in-orbit weight of 4,265 lbs. for a 2,000-lb. payload:

Payload	2,000
Structure	1,290
Guidance, control, power	425
Parachute recovery	310
Retrorocket	240
Total	4,265 lbs.

Pertinent aerodynamic data for ORV, based on Newtonian hypersonic analysis, are presented in Fig. 14. Note that the maximum L/D is approximately 1.4 at a trim angle of 27 deg., corresponding to a fin deflection of 4 deg. (*Continued on page 56*)

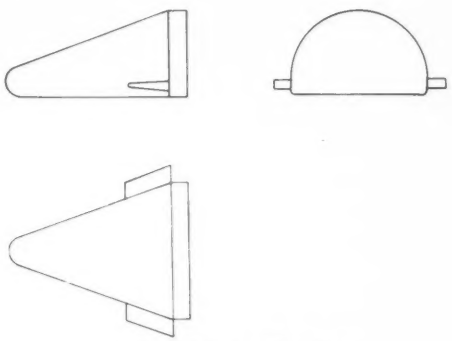


Fig. 13. Vehicle configuration.

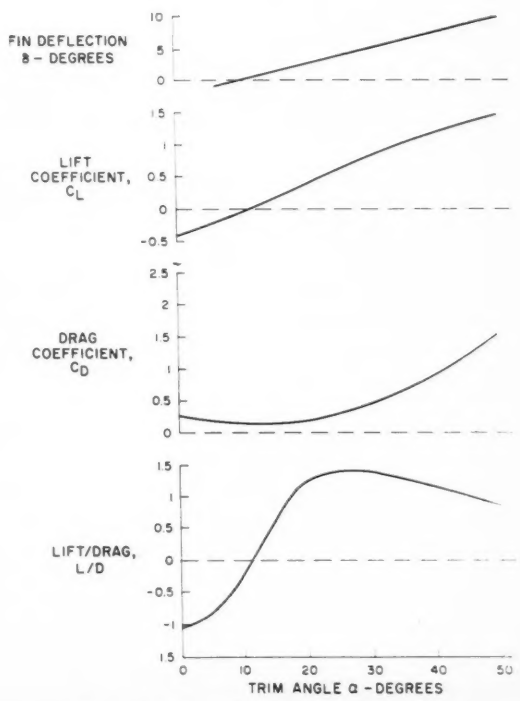


Fig. 14. Configuration aerodynamics (Newtonian).

Anticipating Anti-Skid System

Frederick L. Ryder, MIAS, *Republic Aviation Corporation*

IN THE BRAKING OF airplanes, it is often important to utilize the maximum braking effort just short of skidding, for the purpose of stopping within the shortest possible distance. However, human pilots have no senses by which they can accurately judge this optimum braking effort, particularly because the tendency to skid is highly dependent on ground conditions, of which the most important practical variable is wetness. Hence, in the absence of a skid-anticipating device, the pilot must keep the braking effort below the skidding value by a substantial margin since skidding is a dangerous condition involving possible loss of steering control and serious landing-gear vibration, besides entailing undue tire wear and a substantial loss of braking effectiveness.

A practical device intended to improve this situation is described in reference 1 and is shown here in Fig. 1 in its basic essentials. The d.c. generator G is mounted on a landing wheel so that its output voltage is indicative of the instantaneous angular velocity of the wheel. This voltage is applied to coil C of relay R through a relatively small capacitance so that the current through the capacitance is effectively the time rate-of-change of the generator voltage and therefore is indicative of the angular deceleration of the wheel. For the normal deceleration encountered during a landing run, the coil current is insufficient to move armature A of the relay; however, for the much greater angular deceleration encountered at the beginning of skidding, the value of this current is sufficient to cause the armature to move, in which case suitable contacts (not shown here) are energized in such a way as to cause the hydraulic braking pressure to drop or, alternatively, to notify the pilot that the pressure is excessive.

Dr. Ryder is a member of Republic Aviation Corporation's Scientific Research Staff at Farmingdale, N.Y. A native of New York City, he is considered an authority in the fields of structures, electricity, computers, and engineering management and has had many papers and articles published in these specialties. Holding degrees from New York University (B.S.E.E. and D.Eng.Sc.) and the Brooklyn Polytechnic Institute (M.M.E.), Dr. Ryder was Research Director for Simmonds Aerocessories, and head of an electromechanical department doing guided missile work at Du Mont Laboratories prior to joining Republic in 1956.

Reference 2 describes a system which is roughly similar to the above, but which differs from it in that the inertia moment associated with the deceleration of the skidding wheel actuates a mechanism frictionally connected to the wheel; the mechanism then reduces the brake pressure as before.

Such systems cannot operate unless skidding has actually been initiated. The consequences of a small amount of skidding can be appreciated by a study of Fig. 2, taken from reference 3 and substantiated by Fig. 9 of reference 4. Fig. 2 shows a typical plot of the force F between wheel and ground as a function of the slip S, the latter being defined thus:

$$S = 1 - \omega/\Omega \qquad (1)$$

where ω is the actual instantaneous angular velocity of the wheel, and Ω is its value in free rolling. At $F = 0$, corresponding to free rolling, $\omega = \Omega$ and $S = 0$; when F has its maximum value F_m, then $S = S_m$; and at $\omega = 0$, corresponding to a fully locked wheel, $S = 1$. The finite slope of the rising part of the curve is due to tire stretch; if the wheel were rigid, S_m would equal zero.

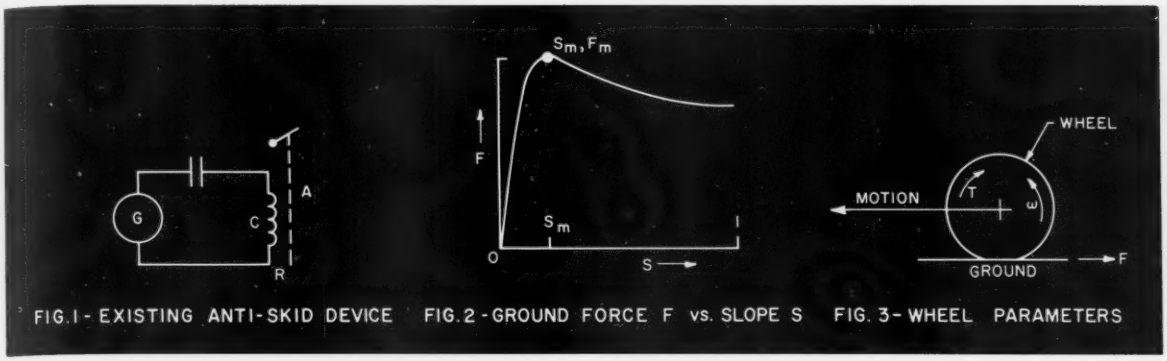


FIG. 1 - EXISTING ANTI-SKID DEVICE FIG. 2 - GROUND FORCE F vs. SLOPE S FIG. 3 - WHEEL PARAMETERS

Introductory theory and schematic for continuous maximization of brake torque without danger of skidding

The relative directions of F, ω, and braking torque T are shown in Fig. 3. The rising part of the curve of Fig. 2 can now be seen to represent a stable relationship since, if ω should decrease monentarily, then S would increase, leading to an increase in F which would restore ω to its former value. An analogous argument shows that the curve is *unstable* beyond the point S_m, F_m. Hence, if the falling part of the curve is entered because S exceeds S_m due to excessive brake torque, then S will tend to increase quickly to the value unity, corresponding to locking of the wheel. This violent tendency would be checked if, as soon as S exceeds S_m, the hydraulic brake pressure could be reduced to a value lower than that corresponding to F_m. This cannot be done in practice, however, because the deceleration at which the system is set to initiate corrective action must be sufficiently greater than the "normal" decelerations so that the latter will not trigger the system. In consequence, corrective action—namely, lowering of the hydraulic pressure—does not occur until the instantaneous operating point on Fig. 2 is well along the falling part of the curve and considerable slowing of the wheel has already taken place. Hence, when the systems described above are operated close to maximum braking capacity for any particular set of ground-surface and aircraft-loading conditions severe fluctuations in hydraulic pressure (and therefore in ground force) commonly result, with attendant undesirable fluctuations in aircraft deceleration and general detraction of the braking effort.

The purpose of this paper is to present a schematic and a theory for a braking control system which is intended to anticipate skidding before the crest of Fig. 2 is actually reached, with consequent elimination of the disadvantages cited above.

Rough Schematic and Basic Theory

The basic idea in the present approach is to sense and control the slope dF/dS on the rising portion of the curve of Fig. 2. This slope is zero at the approach to the skidding condition *regardless of ground conditions and loading of the aircraft.* Its value will be found by applying very small disturbances to the braking system and noting the resulting response; the system is in this sense similar to so-called adaptive systems used in autopilots.

A method of embodying the system is shown by a rough schematic in Fig. 4, where the d.c. generator G must be mounted on a landing wheel but the other components can be placed at convenient locations in the

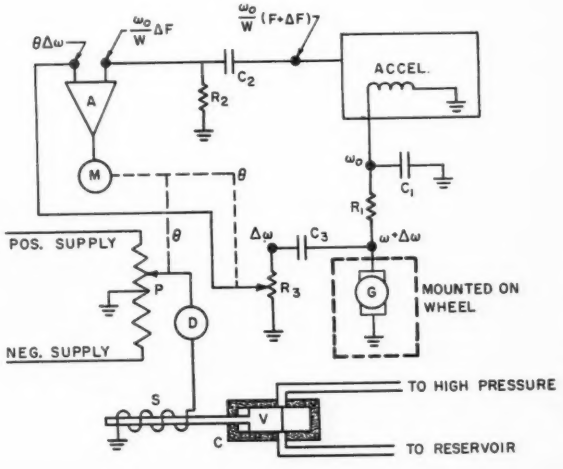


FIG. 4 - ANTICIPATING ANTI-SKID SYSTEM (Rough Schematic)

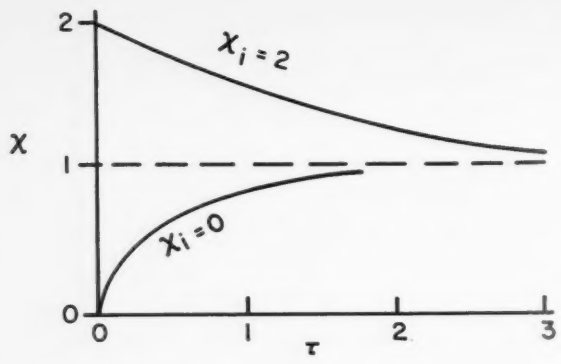


Fig. 5. System response.

fuselage. In explaining this figure, we shall for simplicity omit many constants of proportionality, and shall assume that all braked wheels act identically. Also, we shall limit the present discussion to the more basic relationships; some of the practical design considerations will be mentioned briefly later.

D is a dither generator—that is, a generator of small a.c. voltage—which when applied to the solenoid S sets up a small, periodic, reciprocating motion in valve V. The latter is housed in cylinder C, which is connected between the high-pressure side of the brake hydraulic system and a reservoir. The resulting disturbances in hydraulic pressure produce the following oscillation in wheel angular velocity:

$$\Delta\omega \sin pt$$

where harmonics higher than the first have been ignored; t is time, and p is 2π times frequency. The wheel angular velocity may now be redefined as

$$\omega + \Delta\omega \sin pt$$

The corresponding expression for the slip is

$$S + \Delta S \sin pt$$

where, by Eq. (1), ΔS is negative if $\Delta\omega$ is positive. If we temporarily ignore the mass moment of inertia of the wheel, then the oscillations in ω and F are essentially in phase so that we may conveniently redefine ground force as

$$F + \Delta F \sin pt$$

where, by Fig. 2, ΔF is positive if ΔS is positive (at least along the rising portion of the curve).

The voltage output of the generator G is as indicated (for convenience the a.c. components will be designated only by their *amplitudes*). R_1 and C_1 form a low-pass network, and their values are such that the time-constant R_1C_1 is large compared to the time-constant of transient disturbances in the braking system and compared to the period of dither oscillation, so that only ω_0 appears at the junction of R_1 and C_1, where ω_0 is the equilibrium value of ω corresponding to the applied brake torque. This is applied to the exciting coil of an accelerometer, whose output voltage (the product of excitation and acceleration) is accordingly

$$\omega_0 [(F + \Delta F)/W]$$

where W is aircraft weight, and the landing gear and fuselage are assumed rigid. The time-constant R_2C_2 of the high-pass combination of R_2 and C_2 is assumed relatively small compared to that of transient disturbances (but not compared to the dither period) so that only the dither component of the accelerator output reaches amplifier A, as shown.

The output of generator G is also fed to the high-pass combination R_3C_3, which has a relatively small time-constant so that only the dither component is felt across R_3, which is in the form of a potentiometer. If we designate as θ the displacement of the pot contactor, the resulting voltage applied to amplifier A is $\theta\Delta\omega$, and the amplifier rapidly drives motor M until its own total input signal is zero, at which time

$$\theta = -[(\Delta F/W)/(\Delta\omega/\omega_0)] \quad (2)$$

Designating as S_0 the steady value of S corresponding to ω_0, we find from Eqs. (1) and (2), with Ω eliminated,

$$\theta = [(1-S_0)/W](\Delta F/\Delta S) \approx [(1-S_0)/W](dF/dS) \quad (3)$$

so that θ is closely proportional to the slope of the curve in Fig. 2, as desired.

The above equation takes on a more convenient form if we eliminate W by the following definition:

$$F_m \equiv \mu W \quad (4)$$

where μ is the effective coefficient of friction between wheel and ground at $F = F_m$, and is dependent on ground conditions. Then if we define the *relative* ground force and relative slip thus:

$$f \equiv F/F_m \qquad s \equiv S/S_m \quad (5)$$

Eq. (3) becomes

$$\theta = \mu[(1-S_0)/S_m](df/ds) \quad (6)$$

where the relationship between f and s is undoubtedly less variant, for different airplane weights and ground conditions, than the relationship between F and S. We now select a definite value of θ, say θ_c, such that for most cases it represents a slope which is greater than the skidding value—namely, zero—by a safe amount, and arrange potentiometer P so that its contactor voltage is zero when $\theta = \theta_c$. For other values of θ this voltage, when fed to solenoid S, results in a disturbance of valve V which, to a rough approximation, changes the brake torque at a rate proportional to $\theta - \theta_c$. With the mass moment of inertia of the wheel ignored as before, there results

$$dF/dt = k(\theta - \theta_c) = F_m(df/dt) \quad (7)$$

where k is chosen as a positive constant. This can be solved in conjunction with Eq. (6), if s is suitably related to f. To do this we assume that the rising part of the curve in Fig. 2 is a parabola passing through 0,0 and S_m,F_m and having an initial slope of 2; this

leads to

$$f = 2s - s^2 \tag{8}$$

With Eq. (6) this leads to a convenient expression for θ_c:

$$\theta_c = 2\mu[(1 - S_c)/S_m](1 - s_c) \tag{9}$$

where the subscript c denotes equilibrium values with a brake torque just sufficient to produce $\theta = \theta_c$. Eq. (8) also yields, in place of Eqs. (6) and (7), two new equations in which f is absent. When s is eliminated from these new equations, there is obtained

$$2F_m\left[\frac{(1 - S_c)\,(1 - s_c)}{\theta_c\,(1 - S_0)}\right]^2\frac{d\theta}{dt} = k\left(\frac{\theta_c}{\theta} - 1\right) \tag{10}$$

To simplify this, we introduce the following definitions:

$$\theta/\theta_c \equiv x$$

$$t \equiv \frac{2F_m}{k\theta_c}\left[\frac{(1 - S_c)\,(1 - s_c)}{1 - S_0}\right]^2\tau \tag{11}$$

Eq. (10) then reduces to

$$dx/d\tau = (1/x) - 1$$

Thus θ must always decrease if $\theta > \theta_c$, and increase if $\theta < \theta_c$, as is desired. Integrating the above equation, we find

$$\tau = x_i - x + \log\,[(1 - x_i)/(1 - x)]$$

where x_i is the value of x at $\tau = 0$. Fig. 5 shows plots of x vs. τ, indicating how x approaches unity for two different values of x_i. Effectively, θ reaches θ_c at about $\tau = 3$, and there is no overshoot.

Some Practical Considerations

Constancy of Safety Margin

For convenience we define the safety margin against skidding as $1 - s$, which is the fraction of S_m by which the actual slip would have to be increased to cause skidding. If we assume that Eq. (8), relating f and s, is approximately true for a given airplane under all conditions of ground and loading, then by Eq. (9) the safety margin corresponding to a selected value of θ_c varies with $\mu(1-S_c)/S_m$. The variation in $1-S_c$ may be ignored for the present purpose since the whole range of S is probably less than 0.2 or so. As to the remaining quantities, we reason thus:

(1) The principal effect of increased weight is probably to increase S_m since more tire stretch can be tolerated before skidding occurs.

(2) For wet ground μ will be less than for dry, and S_m may be expected to be smaller because less tire stretch can be tolerated before skidding occurs.

Thus, while the skidding value of θ is zero in all cases, the safety margin for a selected value of θ_c may vary appreciably under different conditions, although it can probably always be kept small. For a plurality of wheels controlled by a single anti-skid system, as is desirable in practice, the safety margin chosen will of course have to be somewhat greater than for a single wheel.

Constancy of System Response Speed

By Fig. 5 the response of the system as a function of τ does not vary seriously for different initial values of x_i. As a function of real time t, however, the response becomes slower as the coefficient of τ in Eq. (11) becomes larger. With the aid of Eqs. (4) and (9), this coefficient is found to be approximately proportional to

$$\theta_c W S^2_m/k\mu$$

Assuming from the previous discussion that S_m is roughly proportional to W and that μ is roughly independent of W, we conclude that, for given choices of θ_c and k, the system response time varies as the cube of the loading; assuming further that the ratio of S_m to μ remains roughly constant as μ decreases because of wet ground, we conclude that the system responds somewhat faster with wet ground than with dry. Hence it may prove desirable to provide for variation of k with different ground and loading conditions.

Constancy of Insensitivity to Noise

Since the system must function effectively over a range of values of ω_0 of perhaps 30 to 1 (corresponding to aircraft speeds from, say, 200 to 7 m.p.h.), the level of the signals admitted to amplifier A in Fig. 4 will vary very greatly even though the dither magnitude ΔF remains constant. Thus the effect of electrical and mechanical noise may be increased significantly at low aircraft speeds, possibly resulting in erratic behavior of the system.

This disadvantage may be overcome by the arrangement of Fig. 6, representing a modification of the generator and of the accelerometer excitation. The components R_1 and C_1 in Fig. 4 are omitted, and a new

(*Continued on page 59*)

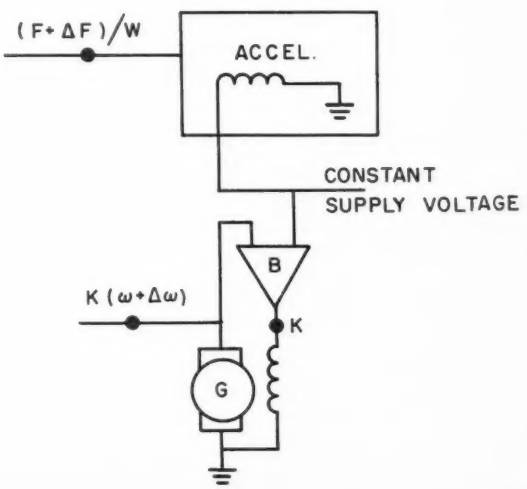


Fig. 6. Variable generator excitation.

"After a brief consideration of available techniques, one is faced with the conclusion that photography is the most practical available technique for space reconnaissance. However, increased effort is needed to extend the state of the art in the photographic field to obtain a 24-hour surveillance capability."

SPACE RECONNAISSANCE

Kermit L. Sandefur, *Hycon Mfg. Company*

In order to survive, information is needed on all real or possible enemy capabilities and intentions. What does the enemy have? Where is it? How many does he have? How does he use it? How good is he at using it? Is he about to use it? Etc. Further needs are for mapping, charting, and weather reconnaissance. "Reconnaissance is a directed effort to secure specific information at a given time within delineated areas."[1] Reconnaissance is thus a part of surveillance—the 24-hour watch over all factors.

It seems rather strange for a country to announce that it is developing—and practicing with—weapons to destroy another country, although this procedure is approved or condoned by most nations; yet the suggestion of an open sky monitoring or a continuous reconnaissance satellite is viewed with concern by some nations. National air space ends some place about 35 miles up, or perhaps just beyond interception altitude. It seems to the writer that reconnaissance satellites operating in the region of open sky would be the best deterrent or advance warning.

Space reconnaissance also includes reconnaissance of bodies other than the earth. In order to study any planet (or moon), the use of image-forming sensors and other sensors is required to obtain data on surface conditions. This article is intended to discuss in general the current state of the art in space reconnaissance and perhaps invoke some critical considerations in the developmental areas.

Specific Information

All reconnaissance sensors can be divided into two classes—image-forming and non-image-forming. The image-forming sensors are photography, infrared, television, "passive radar," and radar. The non-image-forming sensors cover other areas such as temperature, pressure, dust sampling, meteors, magnetic fields, electric fields, etc.

There is a close relationship between military and scientific data collection. Both collection systems are concerned with gathering a maximum amount of data with a high level of accuracy. They differ in the choice of time and location of data gathering. Scientific instrumentation is primarily interested in the accurate measurement of predictable events and in the detection of unexpected events. Military instrumentation is primarily interested in the discovery of new activities and in monitoring known activities.

Image-Forming Sensors

Photographic equipment is considered the most important of all instrumentation proposed for present space missions and for those proposed for the next 10-year period.[2] This is true for several reasons, foremost of which is the fact that a photograph contains and therefore provides more bits of information per pound or per dollar than any other sensor. The notable exceptions are those wherein special data are required which are not obtainable via photography, such as magnetic field measurements.

A comparison of the parameters of the image-forming devices shows why photography has the largest number of bits. Infrared is limited by the optical collector, as is photography, but even more limited in the detector size. Radar is limited by the extremely large antenna requirements to obtain narrow beamwidths and thus small resolution capability. Television is limited by the required optical system, but even more limited by the CRT's phosphor grain size. Photography is limited by optical systems and film grain size. Thus photography has greater information storage capacity through the use of diffraction-limited lenses and high-resolution film.

An alumnus of the University of Kansas, Mr. Sandefur also performed Graduate Assistant work there, during which time he designed and developed a spectrochemical analyzer. Joining Midwest Research Institute as a physicist in 1951, he was project leader on a wide variety of programs before joining Hycon in 1956 as a Senior Physicist. Two years later, he was assigned as Research Physicist and Project Engineer for space reconnaissance programs. Research activities in which he has participated include radiation health physics, fast film processing, and flight testing and optical design for various reconnaissance systems.

Present Capabilities and Limitations of Photography

In aerial photography, pictures are taken of ground objects through long air paths by cameras, lenses, and associated equipment mounted on unstable and translating platforms. The resulting photographic negatives, consisting of nonhomogeneous clumps of silver arranged in numbers and size as to approximate the geometric pattern of reflective of the ground objects, are then printed. Now consider the current state of the art as to what can be done in practice.

In any photographic reconnaissance, there are two basic factors to be recognized. First, the limitation imposed by the film, mostly grain size and speed which, unfortunately, vary in an opposite direction—that is, the finer the grain, the slower the emulsion of the film. Second, the absorption and disturbance caused by the atmosphere. At the altitude at which most reconnaissance will be flown, the bulk of the atmosphere will be beneath the plane. For instance, if you fly at 100,000 ft. altitude, 98.7 per cent of the atmosphere is below you and only 1.3 above (based on the ratio of densities), and all the disturbances due to absorption, temperature gradients, etc., are experienced. There are additional photographic difficulties when above the layers of air glow, noctilucent clouds, and auroral display at about 300,000 ft. and higher.

Camera systems may be evaluated from the standpoint of acuity and sensitivity. Photographic systems are limited by the angular resolving power of the system, the aperture, and factors affecting contrast, such as haze, glare, and subject reflectivity. Systems presently in operation and others in the laboratory can resolve as high as 2 to 3 sec. of arc under ideal conditions. In practice, the factors causing image motion and loss of quality result in resolutions of from 4 sec. of arc to about 1 min. of arc. The systems resolving 1 min. of arc are lightweight and usually cover a wide field of view. The systems resolving 4 sec. of arc are heavy and usually cover a narrow field of view.

Long focal length and large format systems using high-resolution film and lenses yield a laboratory resolution of about 1 sec. of arc. However, in use, these systems require ideal temperature, pressure, and humidity control and very accurate image motion compensation (IMC). The required environmental control may be expected in future space vehicles. The propulsion-off condition in space vehicles will be a great aid in maintaining the relative positions of image and film. The areas of IMC error, air turbulence, and required exposure time remain the limitations to high resolution.

As to a photographic film, even the best available is inferior to the human eye for short exposure times. This has been demonstrated by several astronomers, mostly those engaged in the study of the surface of the moon. At Mt. Palomar with the Hale telescope at full aperture (on the one night a year when the "seeing" is calm enough), film can resolve about half a mile on the moon, while a visual observation of long thin objects resolves about 500 ft.

Film affects resolution and acuity since present high-resolution film (such as SO1213) requires longer exposure times for realistic lens apertures. The ground resolution achievable with these films in any lens system can be found by working from lines per millimeter resolution to lens focal length to angular resolution on graph B and from angular resolution to altitude to ground resolution in feet on graph A. This resolution will be reduced by factors from IMC and stabilization errors, from atmospheric limitations, and from target contrast and geometry effects. Let us now consider photographic sensitivity, a factor closely related to film resolution and grain size. In general, there are four levels of photographic detail as listed in the *Space Handbook*[5] and four corresponding types of photo reconnaissance films available today:

50 to 200 ft ground resolution to identify lines of communication requires extremely fast film, such as Agfa Ispan Record ASA-2000, with coarse gain and low resolution which can yield about 400 ft of resolution from 50 miles of altitude under low light levels.

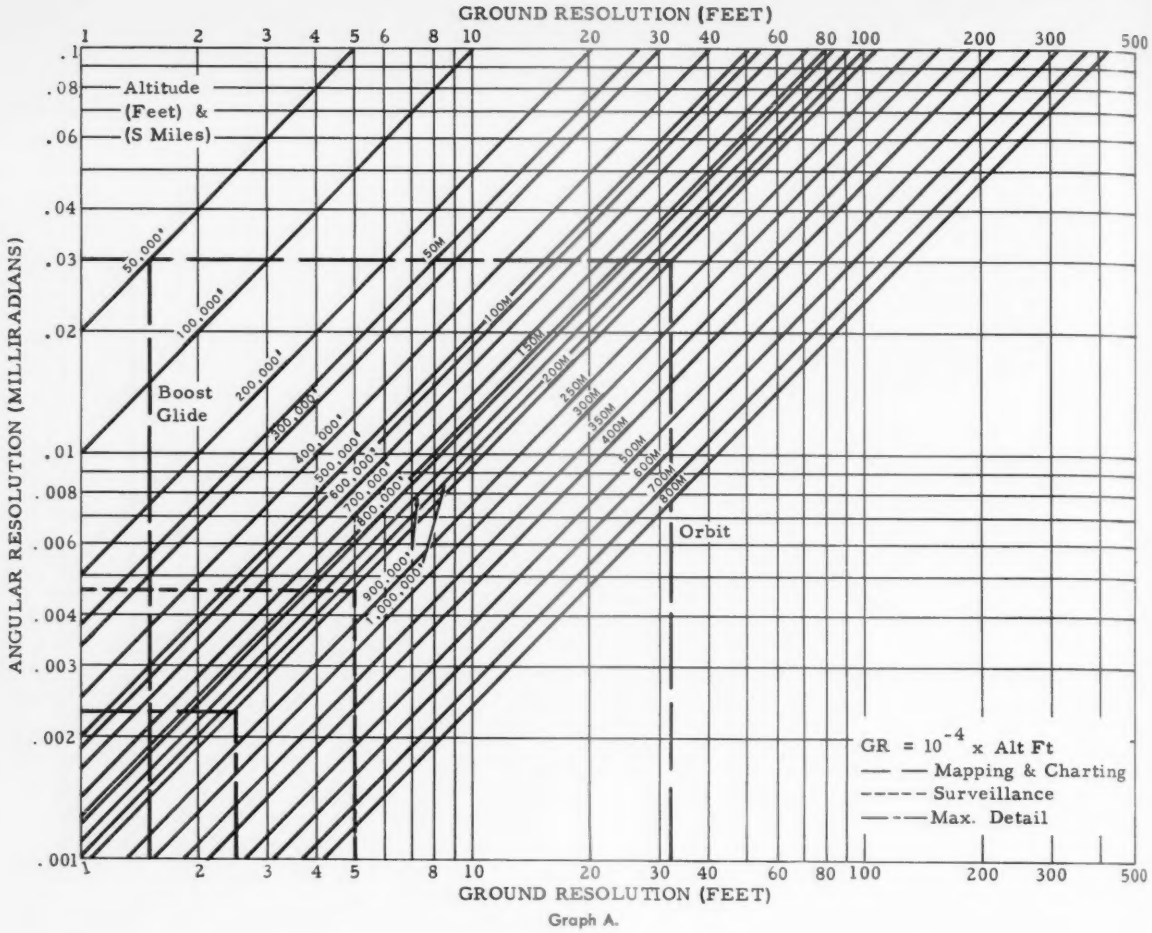
10 to 40 ft. such that aircraft could be seen on airfields. The standard Aercon Tri X, ASA 200 and 40 1/mm., is used for daylight with exposure times of 1/1,000 sec. and a lens aperture of f/8. (See the parameter curve, graph C.)

2 to 8 ft. such that detailed analysis of airfields could be made. The Aercon Plus X, ASA 90 and 60 1/mm., is used in bright daylight with exposure times of 1/100 sec. and a lens aperture of f/8.

0.5 to 2 ft. such that very fine detail about new activities could be made. The new SO1213, ASA 12 and 110 1/mm.—or the new SO1243, ASA 1 and 170 1/mm.—are available for such high-resolution use, but they are very slow. The SO1213 could be used with exposure time of 1/100 sec. and lens aperture of f/2 under bright daylight conditions.

Present Capabilities and Limitations of IR

Limited experience with terrain scanning equipment and published IR pictures of areas such as Long Island,



Graph A.

N.Y., show that at altitudes of from 600 to 50,000 ft. there is a detection capability, by day or night, of gross configurations on the terrain. It must be realized that the wavelengths used (1 to 10 microns) cover the water vapor and carbon dioxide absorption bands, and therefore these wavelengths do not penetrate an appreciable path length. One cannot see through clouds or fog.

Present Capabilities and Limitations of Radar

Experience with radar has shown it to be a most misunderstood technique, with the exception that it does give range data directly. Radar inherently has poor resolution and, in order to approach photographic capability, a tremendous breakthrough in technique is required. To obtain the required narrow angular resolution, the antenna must be of a large dimension, or an indirect means must be used to increase resolution. The required difference in path length for a detectable signal results in unavoidable blank strips directly under the aircraft. The radar system is not passive. The resolution of targets on the ground is about 400 times as coarse as in photography.[3]

On the positive side is the all-weather feature of most wavelength regions. The direct range determination is, of course, the most important single feature. However, the reduction of slant range to ground distance leaves much to be desired in accuracy.

Weather radars, used for various weather studies, utilize the 3.2 cm. radar which shows most precipitation cases quite well, such as snow and the bright band and thick cirrus clouds. Radar operating in the longer wavelength region is free from weather effects.

High-resolution millimeter radar yields detection and recognition of airport runways and large industrial sites. When coupled with aerial photographs of the same area, some reconnaissance value can be obtained.

Present Capabilities and Limitations of Passive Radar

The new area of passive radar, or parametric amplifiers or masers, shows some promise in overcoming some of the objections to radar. This equipment is passive and may be smaller physically, but has the disadvantages of IR techniques in requiring cryogenic equipment and comparable poor resolution like IR.

Present Capabilities and Limitations of Television

TV is fine for low-altitude work, but high-altitude resolution is restricted by the phosphor grain size and the electron optics dimensions; 1,000 TV lines across

the format is current state of the art. On 1/2-in. TV camera tube, this corresponds to 40 photo lines/mm. This resolution does not compete with photography where more than 40 lines/mm. are available across a 9-in. format.

TV does give immediately transmittable reconnaissance information and, in many situations, is the only method available to obtain data. Telemetering bandwidth problems and power requirement problems are yet to be solved.

Present Capabilities and Limitations of Non-Image-Forming Devices

The non-image-forming reconnaissance devices are, in general, sampling data such as temperature, magnetic fields, electric fields, radiation, etc., in the immediate vicinity of the vehicle and are not bothered by the slant range problems like the image-forming sensors. The state of the art here seems adequate.

General Comment

Thus, after a brief consideration of available techniques, one is faced with the conclusion that photography is the most practical available technique for space reconnaissance. However, increased effort is needed to extend the state of the art in the photographic field to obtain a 24-hour surveillance capability.

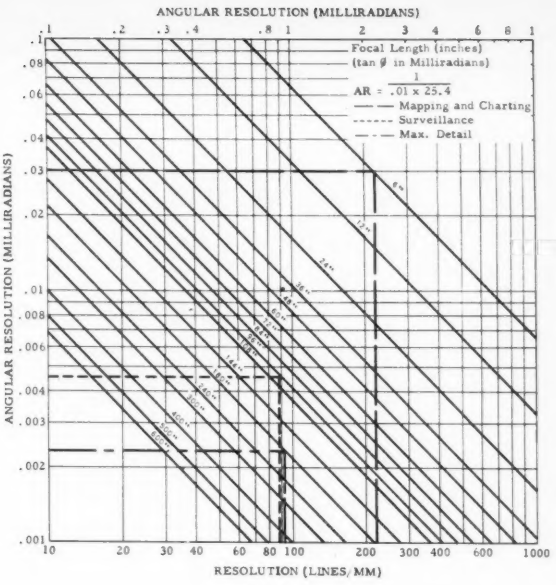
Shape and Contrast of the Target

So far we have discussed only the geometry of the problem. Most targets viewed from high altitude have low-contrast detail. It is a well-known fact that the contrast decreases as altitude increases; however, the exact manner in which this occurs has not been evaluated.

The best assumption possible at the present time is that contrast decreases linearly with increasing altitude above 15,000 ft. In recent discussions, a value of relative contrast given by the following expression was arrived at as the contrast vs. altitude for clear noon daylight. This checks roughly with data at Wright Air Development Division.[4] Relative Contrast = 0.87/Slant Range.

The shape of a target has great influence on its identification and detection. It is well known that a long thin object whose narrow dimension is much smaller than the "resolution element" may be detected and when viewed in context can be identified.[5] Targets as small as one tenth the resolution element are commonly identified in high-altitude photography, provided the length is more than five times the "resolution" element width.

Similar difficulties with shape and contrast exist for radar, infrared, and the other sensors. In the case of infrared, for example, since the electromagnetic emission from the target is a function of both the temperature and the emissivity, a target may "disappear" in the background as the terrain warms or cools, only to appear again later.



Graph B.

Ground Resolution

Graph A allows quick determination of the angle subtended at the sensor by a ground target. Any useful sensor must be capable of resolving this angular dimension. For example, to resolve 10 ft. on the ground from 100 miles of altitude, the sensor must resolve 0.02×10^{-3} rad. An angular dimension of 0.2×10^{-3} rad. will require a 96-in. focal length system with a system resolution of 21 lines/mm. or a 24-in. focal length system with a system resolution of 82 lines/mm.

Other possible focal lengths and their required system resolutions are shown in Graph B.

Scale

The specific information required determines the scale needed. In most applications it is just as bad to have excess information on the photograph (it is distracting) as it is to have insufficient information (it is frustrating).

There are two contributions to photographic scale—the initial scale from the focal length of the lens system and the added scale from enlarging the photograph. The enlargement depends on the grain size of the photosensitive material.

Optimum "working" scale for various types of target is indicated in Table 1.

(Continued on page 60)

Table 1.

Scale 1	Target
5,000	Height and depth determination
7,000	Airfields and aircraft
10,000	Urban area analysis, shipbuilding
50,000	Building counts
100,000	Location of cities
1,000,000	Limit for charting

Support Systems: Part III—In the Future

Richard W. Skulski, *The Martin Company*

DESPITE great advances in technology, the men who design the missile systems of the future will find many problems of greater magnitude and complexity than those found by the pioneers who designed the V-2 or the Viking. An inclusive listing of all the specific problems which will arise is, of course, impossible. It is the more modest objective of this paper to point out some of the most important and general problems which will face the support systems designer of the future.

Missile systems can be placed, broadly, in two non-exclusive classes. First, there are the strategic bombing systems which seek directly or indirectly to deliver a warhead to some distant target. Second, there are the space missions systems which may or may not have a military objective, but whose tasks include a variety of orbital accomplishments or deep space missions. Protective basing and fast reaction times characterize the former, while larger and more elaborate equipment and more sophisticated and unprecedented missions characterize the latter.

In the foreseeable future, hard bases of missile strategic bombing systems will be obsolete. The evolution will be toward mobile basing using submarines, ships, large manned aircraft (perhaps nuclear powered), trucks, or trains. Because of advances in storable, high-energy propellants, missiles will achieve increased ranges and carry larger warheads without an increase in size. The support equipment requirements for these mobile systems will dictate increased ruggedness and multifunctional equipment to keep at a minimum the equipment to be transported. More difficult repair and replacement logistics imposed by increased mobility will demand increased reliability.

The success of space missions planned for the next few decades hinges largely on man's ability to boost large payloads into orbit. The single, most dominating characteristic of the proposed missiles will be their large size. Shipping, handling, erecting, an servicing problems for this type of missile are unprecedented and will require solutions that depart radically from conventional methods. Missile propulsion requirements—demanding hard-to-handle high-energy propellants, nuclear stages, catapult launchers perhaps, booster recovery, and renovating equipment—will pose additional base equipment problems.

Dr. Skulski studied at the Illinois Institute of Technology, where he received B.S. (1949), M.S. (1951), and Ph.D. (1954) degrees in mechanical engineering. As Research Engineer at the Armour Research Foundation (1948–1953), he conducted research in the fields of interior ballistics, blast phenomena, fundamental shock-wave investigations, servomechanisms analysis, and analog computer simulations. At Farnsworth Electronics Co. as Chief Mechanical Engineer, his department was responsible for all mechanical design in the company, including the mechanical ground support equipment for the Bomarc missile. In 1958 Dr. Skulski joined Martin-Denver, where he is presently Head of Base Systems Applied Research, responsible for the identification and solution of base systems equipment problems for future missile systems. Dr. Skulski has published papers on such subjects as supersonic compressible flow, interior ballistics, nuclear reactor operation, automatic data processing, and hydroponics.

High payload missilry for large manned satellites, lunar and planetary probes, soft landing operations, and the establishment of lunar bases presents another aspect of the support systems problem, which again dictates requirements similar to the requirements of large boosters. In addition, manned space stations or moon bases present many new problems. Extraterrestrial bases will dictate new requirements for equipment to operate within new environments, and will dictate requirements for environmental control. New operations such as satellite station construction, lunar base construction, exploration and mining, missile loading and unloading, refueling, and launching from space stations and lunar bases all portend detailed requirements yet to be established and specific problems yet to be identified.

Problem Areas

The most pressing problem areas are presented here according to a somewhat arbitrary division of engineering responsibility.

Mechanical and Fluid Systems

(1) One of the most urgent and challenging problems of missile systems is the transportation, handling, and

This article reviews the trends in weapons systems and space missilry and their effects on requirements for support systems equipment. The most important problem areas of the future for support systems are listed and discussed. These problems are classified according to their mechanical, electronic, architectural, basing, human factors, and operational analysis aspects. No attempt is made to offer design solutions to specific problems.

Cognizance of these trends and effects by the aerospace engineer should result in an orderly and economical evolution in support systems design, construction, and operation.

erecting of large missiles. Projected now on drawing boards are missiles larger than existing road and rail clearances can accommodate—nor can existing aircraft transport the projected configurations. Water transportation, on-site construction, and special offshore launching facilities all offer possible preliminary and intuitive solutions. However, as missiles become still larger, the problem becomes increasingly complex. Optimum transportation, handling, and erecting must involve the actual missile design and construction and to a large extent the launching base configuration and location. Also, the logistics of supply and maintenance cannot be ignored. Only proper analysis of all these areas can minimize the potentially fantastic costs involved.

(2) Future requirements for high-energy propellants make continuous propellant handling research mandatory. Problems of low temperatures, corrosion, instability, toxicity, and hypergolicity must be investigated even before propellant loading systems requirements can be stated. Currently, only limited capability has been achieved for handling small quantities of most of the new propellants for component testing. Much remains to be done if operational components and systems are to be ready in time to meet future missile demands.

(3) Because the cost of large boosters is so great, much thought has gone into making them recoverable. An extension of the problem of expensive booster units has also resulted in the notion of a catapult—a boost device which does not leave the ground at all. Large booster and recovery system costs make a thorough study of boost requirements in the light of feasible catapult configurations well worth while.

(4) Provision of the necessary equipment and facilities to receive returning space vehicles is another aspect of booster recovery and manned space flight that must be considered. Equipment and facility requirements are as yet undefined, but conceivably a shuttle service between a manned satellite station or moon base and the earth could require facilities and equipment ranging from a simple landing strip for skid-equipped glide vehicles to complex landing pads for vertical-descent manned boosters. Special disassembly, handling, and reconditioning equipment to outfit recovered boosters for re-use also will be required.

(5) Space travel will require ground equipment to train men in new skills and accommodate them for new environments. Items such as reaction control simulators and zero-g devices are illustrative examples. Human factors research in a space environment is vital.

(6) Extraterrestrial exploration will require diverse equipment. To build a satellite station or lunar base and to explore the moon, man will need space suits, special tools, personal propulsion devices, special vehicles, mining equipment, etc. A penetrating study of the various probable space operations should yield a list of essential equipment. Preliminary design concepts will be helpful in determining which equipment experiments should be pursued further.

Architectural and Basing

(1) Base planning work must play a vital role in the large missile problem delineated above. Site selection, receiving facilities, special emplacements for handling and servicing, maintenance facilities, etc., must all be provided in the synthesis of any large missile scheme.

(2) Establishing satellite stations and lunar bases requires concentrated study to devise optimum architectural techniques for design and construction. Here again, the problem is complex because of the special and unprecedented nature of these operations and the restrictions on construction manpower and time. Before a successful architectural scheme can be said to exist, virtually every operation of every phase of construction must be analyzed, and the whole integrated with every aspect of the detailed design of the proposed structures. The design and installation of extraterrestrial base facilities—such as power generation and distribution, communications, ecological systems for sewage processing, water supply, air purification, and environment control—must be investigated.

Electronic and Electromechanical

(1) The ability to identify imminent component and system failures automatically, in addition to analyzing a system for existing malfunctions, is demanded in the development of more sophisticated checkout systems. Such improvement will be a necessity on future systems when mission failures will have even more catastrophic results. Such missions and equipment would include all manned missile launches, deep space research mis sile launches, space station launcher and orbiting equipment, and lunar station equipment. The advantages are obvious—namely, increased probability of mission accomplishment, reduced program costs, and accelerated confidence in systems.

(2) Digital techniques will be applied to missile checkout and launch control systems, space station systems, and space transport vehicle systems. Examination of the future requirements of checkout and control systems emphasizes the need to shift from analog to digital systems. For weapon system use, where large numbers of equipment sets are required, it is important that equipment cost and size be reduced as much as possible. With analog systems, cost and size reduction can be achieved by reducing system functions to a bare minimum and thereby accepting a corresponding reduction in confidence in the system. With digital techniques, however, consolidation of equipment to provide a variety of functions can be accomplished, saving money and equipment, without a comparable reduction of the number of checks performed.

Accuracy of measurements will become continually more important in tomorrow's more complex missile systems and control systems. Digital data collection and processing can provide the required high accuracy more readily and at less cost than analog equipment. In addition, remote collection and processing of data from systems under test is simpler to accomplish with digital data processing systems. As more space-oriented developments such as space stations, lunar bases, or deep space probes are undertaken, the need for accuracy will increase because of the large amounts of data to be automatically collected in a relatively short time.

Further, it should not be overlooked that some extremely simple digital equipment can be developed to check out and control airborne digital systems. The importance of this development is evident when it is understood that digital systems are being used more and more extensively in missiles and equipment to be carried in satellites and space stations. However, digital conversion is not required, and optimum use of complementary circuitry is possible.

(3) Interconnecting cabling for remote operations such as checkout and control is at its limit of complexity on existing systems. Cabling will be impossible on some future systems, such as remote space station checkout from the ground.

Methods for transmitting data from a system under test to an evaluation system must be investigated. Applicable systems such as ground microwave systems or standard telemetry systems may exist. However, new methods for specific applications, such as earth current transmission for ground to ground use, should be considered. Remotely operated missile test complexes, mobile or fixed operational weapon systems, space vehicles, and space or lunar stations are systems for which the elimination of interconnecting cabling would be required.

(4) Considering the trend toward mobile weapon systems, special design techniques must be developed for electronic support equipment in order to achieve optimum equipment reliability, transportability, and logistics. Processes which will permit reduction in equipment size, reduction in power requirements, and standardization of replaceable modules must be investigated. Mobile weapon systems will produce new ground equipment requirements. One important requirement for inertially guided missiles will be a ground navigation system that can generate launch point coordinates and initial reference coordinates, azimuth and vertical, for transfer to the airborne computer and platform.

(5) The increased skill levels and training requirements demanded by advanced missile missions require training equipment and devices of great variety. Training techniques developed by human engineering research will serve as a basis for design criteria.

(6) In addition to the "improvements" development described above, completely new checkout equipment philosophies need to be developed to cope with the increased complexity of future electronic systems. One new approach which should be investigated is that of providing a checkout method which could analyze a new system under test and derive its own methods of checkout, determine its own limits and weight factors, and establish an optimum sequence of operations. Currently, the best approach seems to take behavioral or brain models as the starting point.

Such a system will require (a) sensory elements for detecting all pertinent parameters of the system under test; (b) evaluation elements for analyzing the parameters sensed in relation to the degree of success of system operation; (c) logic elements for determining the importance of various parameters to successful mission accomplishment and memory elements for retaining results for future use; (d) computational elements for deriving parameter limits; and (e) various other control and communication elements.

It is reasonable to assume that a system including the above elements could display a simulated intelligence which would enable the machine to determine what is required for checkout, to make the necessary adjustments to its operation, and to exercise judgment in performing optimum checkout of a system under test.

Application of a full-scale system of this type would be most beneficial in a new development program. Provisions would be made to install the checkout system sensory elements in the system under test. The checkout system would adjust itself to establish the optimum test parameter combination within the limits of its sensory elements. The test routines derived by the development configuration probably could be employed operationally with only a portion of the development checkout system equipment.

Human Engineering

(1) The complex space missions of tomorrow will require that space men swiftly absorb large amounts of information for evaluation and decision. Visual means of data presentation offer the best potential for coping with this problem. Research experimentation must be done in the following three areas of data classification:

(a) Exploration of new techniques for displaying information relating to space orientation and navigational control using coordinate reference systems radically different from those used in conventional flight, and information from multiple sources so that decisions relating to the employment of defensive and offensive weapons can be made.

(b) Determination of criteria for the display and communication of such complex data as that received by radar and infrared reconnaissance and terrain clearance information by exploring the effect on operator performance of electronic and optical augmentation, selective filtering, and integration of multiple sensors.

(c) Determination of the design characteristics of display systems necessary for the representation of military space operations to command personnel stationed on the earth.

(2) The design of equipment to train missile personnel and maintain skill levels must be preceded by the development of techniques for proficiency measurement and evaluation of personnel involved in new weapon systems. In addition, methods must be developed for training and sustaining critical operator and maintenance skills to be performed under unusual conditions such as are found in operation or maintenance of space vehicles and for sustaining little used, but highly critical, skills at peak efficiency during the course of long-term missions.

(3) The development of equipment to protect men and equipment from excessive heat or cold, ionization, toxicity, and other environmental extremes, either terrestrial or extraterrestrial, must be based partly on the results of human factors research. The effects of environmental conditions on human beings must be determined and design criteria established.

Operations Analysis

(1) In conjunction with the design problems associated with very large missile systems, operational analysis must be provided to determine optimum criteria for design of missile, ground equipment, facilities, and base. As missiles grow larger, the costs—as well as the degree of interdependence of missile design, handling equipment, site selection, base design, mission, maintenance philosophy, logistics, etc.—grow enormously. If such missile systems are to be at all within economic reach, rigorous analysis of all these factors must be made to achieve maximum dollar value.

(2) Operational analysis is also required for the basing problem of bombing systems. Essential factors that must be considered, besides cost, are operational readiness and survival ability. All of the factors listed above must be taken into account. However, the entire problem becomes more complicated because of mobility considerations.

(3) The problems of logistics, checkout, and maintenance philosophy become increasingly complex as attention is focused in turn on bases for very large missiles, equatorial launch sites, satellite stations, and lunar bases. A good deal of analysis and planning must be done before any confidence can be placed in decisions on how to accomplish these unprecedented tasks.

Conclusion

While this paper has not attempted a complete list of specific problems which space engineers of the future will encounter, it is hoped that some of the more general and important problems have been suggested. By no means can all of the problems be foreseen which will emerge as missile technology advances. However, anticipation of future needs is vital. Just as solving problems of the V-2 or the Viking has led us to our present level of accomplishment, so today's technology will make us capable of recognizing and solving future problems as yet undefined and difficulties yet unimagined.

(*This paper concludes a three-part series begun in July; Part II appeared in September.*—ED.)

✦ ✦ ✦

start from a satellite orbit about Earth with an initial weight of 9,000 lbs. With an optimistic mission analysis, the chemical rocket is barely able to carry the SNAP-8 power plant, leaving no room for additional equipment. The nuclear rocket with a specific impulse of 800 sec. could carry over 1,000 lbs. of additional equipment, while the electric rocket could carry SNAP-8 and more than 3,000 lbs. of additional equipment. The trajectory for the electric rocket in this mission was the Irving and Blum type,[21] where the specific impulse and thrust are varied with constant power. The electric rocket was assumed to be an ion rocket, which will be discussed later, and the efficiency of the ion rocket engine was assumed to decrease sharply in the lower range of specific impulse.[18] Electric rockets with higher efficiency at lower specific impulse would increase the electric rocket performance for this mission.

Deep solar system probe missions will be very efficiently performed by electric rockets. Stuhlinger[19] has considered a number of such missions, and his results are summarized in Table 1. It is evident that electric rockets would have very fast trip times compared with chemical rockets; in addition, a powerful electric power source would be available for communication with distant Earth.

Manned interplanetary flight has been discussed in previous sections with regard to mission analysis, power-plant design, and vehicle design. Moeckel[11] has estimated the performance of the electric rocket and the nuclear rocket for the eight-man round-trip mission to Mars, and the results are shown in Fig. 10. Both rockets are assumed to start from a satellite orbit about Earth, and return to that orbit. It was assumed that the nuclear rocket would have a specific impulse of 1,000 sec. and a nuclear rocket engine weight of 20,000 lbs. Two trajectories[22] were used for the nuclear rocket; a direct transfer for the outward trip and an aphelion route (passing outside Mars orbit) for the return trip were used for the longer trip times, and for the shorter trip times both outward and return trips were perihelion routes (passing inside Earth orbit). Moeckel's fast indirect trajectory was used for the electric rocket performance analysis, and it was assumed that $W_{pp}/W_0 = 0.2$ and that $\alpha = 5$ or 10 lbs./kw. Both spacecraft were assumed to carry 10 lbs./day/man of expendable supplies and a 40,000-lb. auxiliary rocket vehicle for exploration of Mars surface by some of the crew. Further analysis may find even faster flight paths for the electric rocket but, even on the basis of the results shown in Fig. 10, the trip time for the nuclear rocket will be longer than that for the electric rocket if both have the same initial weight. Although more detailed studies will be necessary before final judgment can be made, the comparison shown in Fig. 10 suggests that the nuclear rocket might be competitive with the electric rocket for manned interplanetary flight to Mars or Venus if short trip times are imperative and if high initial weight is acceptable. For longer missions, it appears that the electric rocket will be clearly superior.

Electric Rocket Engines

The part of the electric propulsion system that converts electric power into thrust can be called the electric rocket engine and can be classified into three general types:

(1) Electrothermal rocket engine—in which gaseous propellant is electrically heated, then thermodynamically accelerated rearward to obtain forward thrust. Examples of this type are the arc jet and the resistance heater jet.

(2) Plasma rocket engine—in which ionized gas (plasma), consisting of a mixture of electrons and ions, is accelerated rearward by electromagnetic fields.

(3) Ion rocket engine—in which ions are accelerated rearward by electrostatic fields, with electrons later injected into the exhaust.

This nomenclature is perhaps not perfect, and others might be preferable (such as electrothermal, electromagnetic, electrostatic); however, these definitions will be followed here. Each of these types of electric rocket engines has its problems and its range of efficient operation, and each is at a different state of development. The remainder of this article will be devoted to discussion of these items.

The efficiency with which an electric rocket converts electric power into useful thrust can have a marked effect on the overall spacecraft performance for any particular space mission. For example, a decrease in engine power efficiency lengthens the time required for satellite-raising missions.[23] The effect of electric rocket engine power efficiency on a satellite-raising mission is shown in Fig. 11. The parameters chosen for this mission were initial orbit, 300 nautical miles; final orbit, 19,350 nautical miles (24-hour period); W_0, 6,000 lbs.; W_{pp} 2,000 lbs.; generator output power P, 30 kw. The payload capacity is plotted against raising time in Fig. 11 for a range of specific impulse and electric rocket engine power efficiency. For a given specific impulse, decrease in power efficiency has little effect on payload capacity but seriously increases raising time.

When an electric spacecraft is designed for maximum payload capacity and the mission proceeds with constant specific impulse, then Eq. (5) may be used to determine the optimum specific impulse and maximum payload. The effect of electric power efficiency on the initial weight ratio W_0/W_{pp} is shown in Fig. 12 with $(g_c \sqrt{\alpha}\, T \sqrt{t_p})/(2W_0)$ as a parameter. For low thrust ($T/W_0 < 10^{-3}$), $t_p T/W_0$ is approximately constant[24] so that the parameter in Fig. 12 is proportional to $\sqrt{\alpha}/\sqrt{t_p}$ and the power efficiency has the greatest effect on initial weight ratio for electric spacecraft with heavy power plants and short missions.

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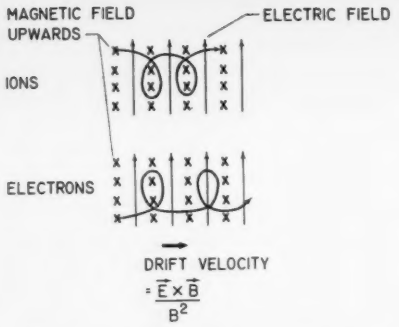


Fig. 19. Motion of ions and electrons in crossed electric and magnetic fields.

The other performance characteristics required for electric rocket engines are high specific impulse, small physical size, low weight, reliability, and possibly variations in specific impulse and thrust such as shown in Fig. 5. These performance characteristics will be discussed with regard to each type of electric rocket engine in the following sections.

Electrothermal Rocket Engines

The electrothermal rocket engine is expected to have good performance up to specific impulse values of about 1,200 sec. High gas temperatures are required to obtain such values of exhaust velocities by thermodynamic expansion through an exhaust nozzle. At high gas temperature, much of the power put into the gas is absorbed in dissociation and ionization of the gas and, if this power is not recovered by recombination during the time the gas flows through the nozzle, a substantial loss will occur. Based on this effect alone, an estimate has been made[18] of the power efficiency obtainable with electrothermal rocket engines using hydrogen or helium propellant, as shown in Fig. 13. The curves assume frozen flow—i.e., no recombination—through the nozzle and assume that all of the electric power is transferred to the gas by the arc or heat exchanger; these curves do not account for radiant heat loss to empty space through the exhaust nozzle. To approach the performance shown in Fig. 13, regenerative cooling of the nozzle and electrode or heat exchanger may be necessary.

An example of the "arc-jet" electrothermal rocket (often called the "plasma jet") is shown in Fig. 14.[25] Propellant gas is passed through the electric arc formed between cathode and anode and is expanded through the nozzle to high velocity.

A diagram of a heat-exchanger electrothermal rocket is shown in Fig. 15. Propellant gas would be passed through a tungsten heat exchanger that would be electrically heated. The hot gas would then be expanded through the nozzle to obtain thrust. A rocket of this type is presently being prepared for experimental research at the Lewis Research Center.[25]

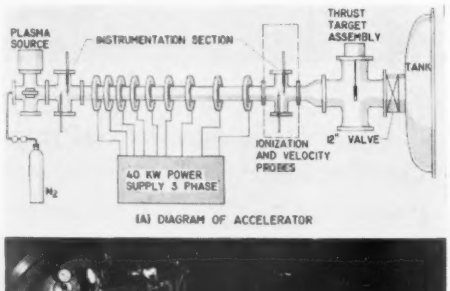
The electrothermal rocket engine receives considerable interest as a simple, practical propulsion unit for satellite orientation, orbit adjustment, and satellite-raising missions. As shown in Fig. 11, power efficiency has little effect on payload capacity so that the use of an electrothermal rocket at 2,000-sec. specific impulse in a satellite-raising mission would provide a substantial payload capacity (in addition to power-plant weight) if a longer propulsion time were not objectionable.

Plasma Rocket Engines

Although plasma rocket engines are still in a very early state of research and development, it is expected that they will have good performance in the range of specific impulse above 1,200 sec., thereby filling the performance gap between electrothermal rocket engines and ion rocket engines. In addition to this important expectation, the plasma rocket can provide (at least, theoretically) a higher thrust per unit exhaust area than the ion rocket; furthermore, the plasma rocket might be more adaptable to integration with future thermonuclear (fusion) power sources. For these reasons, the plasma rocket is receiving considerable research attention, as discussed in summary papers by Evvard[26] and by Moeckel and Rayle.[18]

The mathematical description of acceleration of real plasma by electromagnetic fields is very complex and not well understood at present. Only a simple explanation of plasma acceleration will be possible here. When a charged particle moves through a fixed magnetic field, a force is exerted on the particle in a direction normal to the plane in which the velocity and magnetic field vectors lie. In a similar sense, a force will be exerted on a charged particle at rest with a magnetic field moving past it. The force exerted on the particle may be used to accelerate the charged particle.

This principle may be illustrated with the diagram of an arc-rail accelerator shown in Fig. 16(a). The arc drawn across the rail electrodes consists of charged particles, electrons, and ions moving (in opposite direction) across the gap. If a fixed, external magnetic



(A) DIAGRAM OF ACCELERATOR

(B) PHOTOGRAPH

Fig. 20. Traveling-wave plasma accelerator.

field is applied to the system in a direction normal to the plane of the rails, forces exerted on both ions and electrons will cause the arc to accelerate along the rails. When the first arc leaves the end of the rails, a second arc is struck and accelerates to the right in turn. An intermittent thrust could be obtained from such a device since the ionized propellant forming the arc has been accelerated rearward. Stanley Domitz, of Lewis Research Center, has obtained high exhaust velocities with the arc-rail accelerator shown in Fig. 16(b), but the analysis and measurement of power efficiency and thrust is so complex that an evaluation of this device is not yet complete.

Another plasma accelerator using parallel electrodes is the exploding-wire-rail accelerator shown in Fig. 17. In this device, very large currents from a capacitor discharge vaporize a metal wire placed across the rails. The high current induces a magnetic field which is of greater strength inside the current loop so that the dense, ionized wire material is accelerated along the rail electrodes. To prevent serious power losses, the rail electrode length must be matched with the ringing frequency of the discharge. Preliminary measurements made by George A. Wise at Lewis Research Center have indicated specific impulse values of over 1,000 sec. with this accelerator, but it is not certain yet that all of the propellant reached this value.

The arc-backstrap plasma accelerator is shown in Fig. 18. By having the discharge current from the capacitor flow through the "backstrap" conductor immediately behind the arc, the magnetic field "pressure" is enhanced.[27] Preliminary measurements by Raymond W. Palmer of Lewis Research Center have indicated specific impulse values up to 4,000 sec., where again it has not been determined as yet whether all of the propellant has been accelerated.

The preceding plasma accelerator schemes have strong current arcs or plasma discharges that are notably prone to sputtering of the electrode material. For long-duration propulsion, either sputtering losses must be minimized or continuously renewable electrodes must be used. A plasma accelerator that does not have such discharges is under investigation at the Langley Research Center. This device may be called an "E cross B" plasma accelerator, since it uses both electric and magnetic fields normal to each other. Both ions and electrons have a drift velocity in the same direction in crossed electric and magnetic fields, as shown in Fig. 19. If the plasma is of a low density, its individual charged particles may have trajectories such as shown in Fig. 19, and a general acceleration of the plasma will result.

Another type of plasma accelerator that does not require strong discharges is the traveling-wave plasma accelerator shown schematically in Fig. 20(a). By proper synchronization of the time-varying magnetic fields produced by the coils, a magnetic field "wave" can be made to move along the accelerator tube. Plasma would be trapped in the troughs of such waves and accelerated rearward to obtain thrust. Because of the high exhaust velocities required, and for a reasonable accelerator tube length, the magnetic fields must be varied at radio frequencies. Robert E. Jones, of Lewis Research Center, has performed preliminary experiments with a simplified configuration and has measured specific impulses of 1,000 sec. The configuration shown in Fig. 20(a) is now undergoing preliminary tests at the Lewis Research Center and is shown installed in a vacuum facility in Fig. 20(b).

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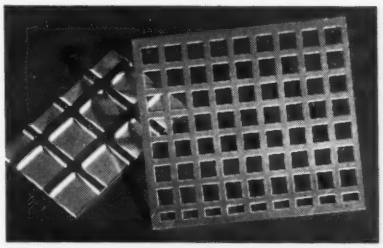

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TRADE MARK

Ion Rocket Engines

The ion rocket engine is at present further along in research and development than the plasma rocket engine. Precise measurements have been made of specific impulse, power efficiency, thrust, and propellant utilization efficiency of a number of different engine design concepts; these concepts continue to show definite promise of good performance. In addition, some other design concepts have good theoretical promise although these have not received so much research attention as yet.

A simplified diagram of an ion rocket engine is shown in Fig. 21. Propellant is ionized in the ionizer—that is, one or more electrons are removed from each propellant particle, and the electrons are pumped away by the electric generator. The ionized particles thus formed are then accelerated from the ionizer rearward through the exhaust aperture of the engine. This acceleration may be accomplished by maintaining the ionizer at a high potential and the last accelerator

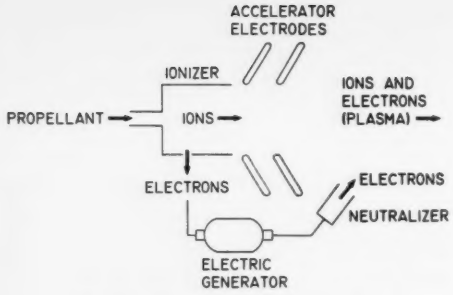


Fig. 21. Diagram of ion rocket engine.

electrode at zero potential so that the ions fall through the electrostatic field to very high velocity. Since each ionized particle has a potential field surrounding it (theoretically, to infinite distance) because of its electric charge, the local potential just downstream of the accelerator could build up to high values if the ions were allowed to form a long beam behind the engine. (High potentials outside the engine would prevent ions from leaving the engine.) This problem can be overcome in theory by injecting the electrons (which have been pumped through the generator) into the ion beam so that the negative charge of the electrons will neutralize the positive charge of the ions in the exhaust beam. (Electron-ion recombination rates are too slow to provide adequate neutralization.) The electrons must be injected into the beam at near ground potential, so the power consumed in the whole process can be thought of as the power required to force the electrons from the high potential of the ionizer to the ground potential at injection.

This simple picture of the ion rocket appears quite straightforward, but many problems exist. For instance, electrons emitted from a surface having a temperature of 1,000°K. have a most probable kinetic energy of about 0.086 electron volts, which corresponds to an electron speed of 1.7×10^5 m./sec., or a specific impulse of 17,000 sec. If the exhaust beam is to have a zero net charge density, the electrons must have the same axial velocity as the ions. (The ion and electron currents must be equal to preserve charge neutrality on the vehicle.) As pointed out in previous sections, electric rockets will be required to operate at a specific impulse (of the ions) much less than 17,000 sec. for many space missions. Since 1,000°K. is a low temperature even for coated, low-work-function electron emitters, it is apparent that an electron-ion velocity matching problem exists in the neutralization process.

Another problem area in the ion rocket engine is the acceleration process. The trajectories of ions falling through the accelerator must be carefully controlled to avoid impingement on the electrodes. A high-velocity ion that hits an electrode may sputter many atoms, and electrode life is important on long-duration space flights. Ion optics are further complicated by the presence of many other ions falling through the accelerator since the space charge effect cannot be neutralized in the accelerator as in the exhaust beam. As the ion charge density increases, the space charge effect becomes greater so that, at the ionizer where the ions are still at low velocity, the space charge can limit the flow of ions from the ionizer.

To illustrate this effect, the Child-Langmuir law defines the maximum (space-charge-limited) current density j_s (amp./m.^{2}) of charged particles that can pass between parallel, plane electrodes with spacing L and potential differences ΔV (mks. units):

$$j_s = 5.563 \times 10^{-12} \sqrt{e/m}[(\Delta V)^{3/2}/L^2] \qquad (6)$$

where e is the electronic charge on each particle and m is particle mass. If it is assumed for the moment that the real ion accelerator can be approximated by the Child-Langmuir law, then L represents the accelerator length. Since the charged particle velocity is

$$v = \sqrt{2(e/m)\Delta V} \qquad (7)$$

then the space-charge-limited current density may be written

$$j_s = 1.967 \times 10^{-12} (m/e)(v^3/L^2) \qquad (8)$$

By using Eq. (1) for thrust and noting that $\dot{m} = jAm/e$, the thrust per unit cross-sectional area of the accelerator is

$$T/A = 1.967 \times 10^{-12}(m/e)^2(v^4/L^2) \qquad (9)$$

In a preceding section, it was shown that the exhaust velocity was specified by the mission so that the thrust per unit exhaust area is only a function of mass-to-charge ratio and accelerator length (within the practical bounds of allowable potential gradient). As will be shown later, this space charge limitation in the accelerator is a serious problem for some engines and missions, and the accelerator length in some ion rocket engines must be as short as a few millimeters.

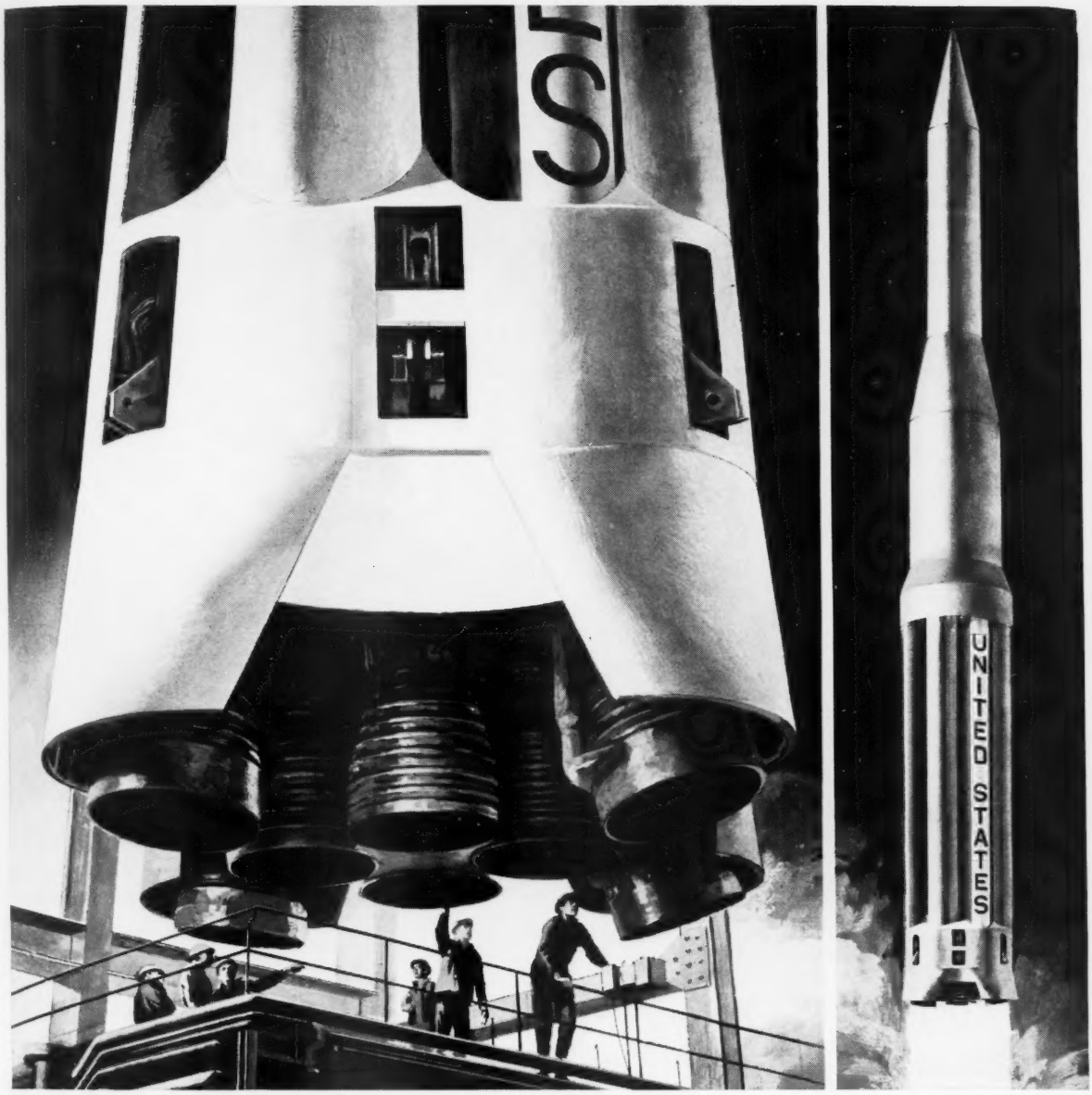
The ionization process also presents some major problems. The propellant escaping the ionizer without an electric charge will not be accelerated. In addition, charge exchange between such neutrals and accelerating charged particles can destroy carefully planned ion trajectories and cause serious electrode sputtering. For acceptable power efficiency, the energy consumed in ionizing each particle must be small compared with the energy of the particle after acceleration.

The problems discussed above are common to most ion rocket design concepts and will be discussed further in subsequent sections under three general types of ion rocket engines:

(1) Colloidal-particle ion rocket engines, where propellant particles consisting of many molecules are charged and accelerated electrostatically.

(2) Electron-bombardment ion rocket engines, where propellant atoms are ionized by collisions with electrons and the resulting positive ions are accelerated electrostatically.

(3) Contact-ionization ion rocket engines, where propellant atoms are ionized by contact with hot surfaces and the resulting positive ions are accelerated electrostatically.



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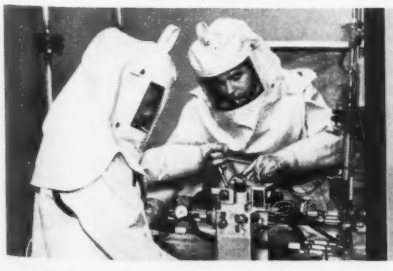

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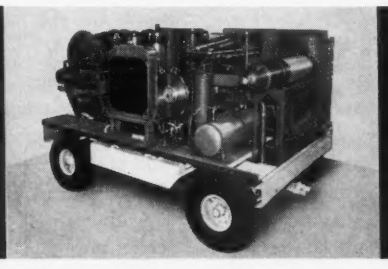

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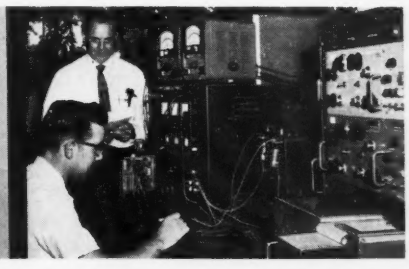

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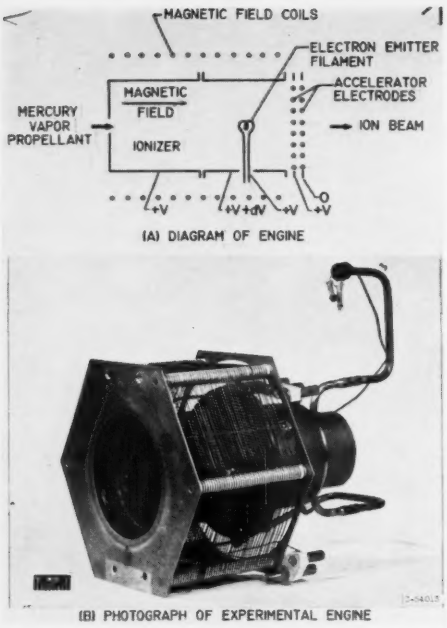


Fig. 22. Electron-bombardment ion rocket engine.[20]

Colloidal-Particle Ion Rocket Engines

As shown by Eq. (9), the thrust per unit exhaust area of a simple ion rocket engine is proportional to the square of the mass-to-charge ratio of the charged particles. If lithium were used as a propellant and were only singly ionized, the exhaust area of the ion rocket engine would be so great that the shadow shielding of a spacecraft, such as shown in Fig. 7, would be very large and heavy. As an alternate to massive atoms such as cesium and mercury, it has been proposed that particles consisting of many molecules might be used as a propellant. Such particles would have an upper limit in size since for a given exhaust velocity the accelerating potential is directly proportional to the particle mass, as shown by Eq. (7). For example, to obtain a specific impulse of 1,000 sec. with a singly charged colloidal particle of 0.01-micron (4×10^{-7} in.) diameter, a 50,000-volt accelerating potential would be required; while a diameter of 0.001 micron (4×10^{-8} in.) would require only 500 volts. Since the accelerating potential is proportional to the square of the specific impulse, as shown by Eq. (7), potential gradients within the colloidal-particle ion rocket engine could become so great that electric breakdown would limit the exhaust velocity or, worse yet, the high potential gradient might limit the number of charges a particle could hold.

In a very interesting theoretical analysis, D. Langmuir[28] has shown that, if the charge on a particle could be changed during the acceleration process, the problem of high potential gradient could be avoided by placing successive accelerators in line. Furthermore, if the particle charge could be removed after the first accelerator stage, followed by a drift (second) stage, and then a greater charge added at the beginning of the third stage, an alternating voltage could be used; in this way, the problem of high overall voltage requirements of the electric powerplant could be avoided.

The charging process in the colloidal-particle ion rocket engines may also be a major problem. At present, it is not clear whether adding or subtracting electrons to, or from, the particles will be the best method.

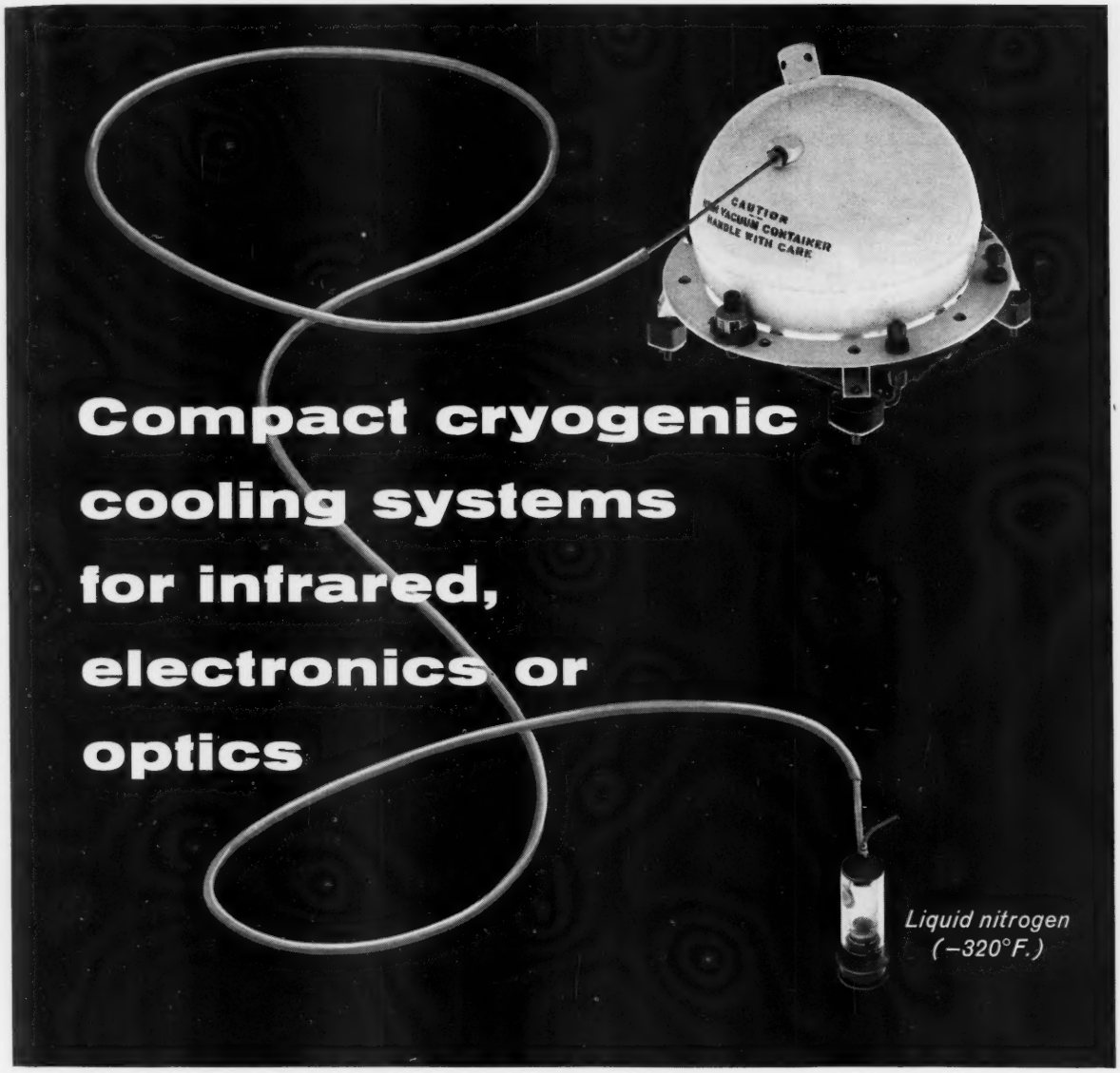
Generation of colloidal particles of such small sizes is complicated by the requirement of a very narrow size distribution (so that all particles will have nearly the same exhaust velocity). Carl T. Norgren, of Lewis Research Center, has successfully generated colloidal particles (from $HgCl_2$ or $CoCl_2$ vapors) which have narrow size distributions with a mean diameter of 0.02 micron. Norgren is at present working with experimental equipment that includes the particle generation, particle charging, and particle acceleration processes.

Although the colloidal-particle ion rocket engine is still in the early stages of research, it appears to have good promise of being a small-size electric rocket engine with good performance.

Electron-Bombardment Ion Rocket Engine

As mentioned in a previous section, the ionization process in the ion rocket engine must be accomplished with a low expenditure of power and a low loss of neutral atoms. Of the many ways of ionizing atoms, the electron-bombardment and contact-ionization methods theoretically have the lowest power consumption and best probability of ionizing all propellant atoms. In the electron-bombardment ion source, ionization of atoms occurs through collisions of electrons with the neutral atoms—that is, as a result of the collision between a high-velocity electron and a slowly moving neutral atom, some of the kinetic energy of the moving electron is expended in tearing another electron loose from its orbit in the atom, thereby leaving the atom with a net positive charge. Because of the low electron-ion ionizing cross section, the high-velocity electrons require many "passes" at the neutral atoms before an ionizing collision can take place (in the average sense of probability). Early electron-bombardment ion sources, such as the Von Ardenne ion source,[29] use electric arcs to provide the high-velocity electrons and strong magnetic fields to cause the electrons to follow a spiral path, thereby increasing the electron path length and increasing the probability of an ionizing collision before the electron reaches the anode. In a very recent research project, Harold R. Kaufman of Lewis Research Center has demonstrated that an electron bombardment source without an arc, and with very low magnetic field strength, can be a very efficient source of ions for electric rocket engines.[30]

A diagram of Kaufman's electron-bombardment ion rocket engine is shown in Fig. 22(a), and a photograph of the experimental engine is shown in Fig. 22(b). Mercury vapor propellant flows into the ionizer chamber, where it is ionized by electrons from the



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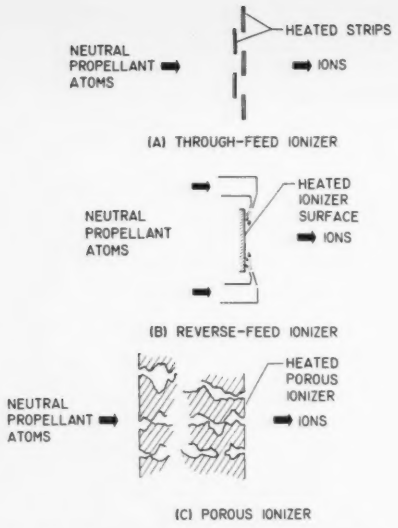

Fig. 23. Contact-ionization ionizers for ion rockets.

electron emitter. The magnetic field causes the electrons emitted from the filament to gyrate, and collisions with atoms and other electrons allow the electrons to drift to the portion of the wall held at a slight potential above the accelerating potential V. Ions formed by this process are given a small velocity toward the screen grid (an array of parallel wires) by the potential dV. From the plane of the screen grid, the mercury ions are accelerated by the potential difference V between the screen and accelerating grid electrodes. The energy expended in the ionization process is primarily the power required to emit and accelerate the ionizing electrons, and the power necessary to maintain the weak magnetic field.

Although this ion rocket engine is in the preliminary stages of research, it has consistently operated with good performance. For example, at a specific impulse of 5,500 sec., the power efficiency is 69 per cent, and 83 per cent of the mercury atoms are ionized and accelerated. Modifications to this experimental engine are now being made, and considerable improvement of its performance is expected.

Contact-Ionization Ion Rocket Engines

In one of his early papers, Stuhlinger[3] suggested that contact ionization might provide a suitable ion source for ion rocket engines. Experimental physicists such as Irving Langmuir and J. A. Becker had done much research dating back to the 1920's which showed that alkali metal atoms could be singly ionized upon contact with surfaces such as tungsten and platinum. Because of the low ionization potential of the alkali atom, an electron from the atom becomes trapped in the high-work-function surface so that, when the atom evaporates from the surface, the electron is left behind and the atom has a net positive charge. For this process to occur, the work function of the surface must be larger than the ionization potential of the atom, and, since the presence of surface films of alkali atoms considerably reduces the work function, the ionizing surface must be only lightly covered at any instant (say 1 per cent coverage). To obtain practical values of ion current density from such surfaces, the residence time of the atom on the surface must be short—i.e., high evaporation rates—so that the surface temperature must be high. For the current densities required of ion rocket engines, tungsten surface temperatures must be about 2,000°F. when cesium is used as a propellant. [The cesium-tungsten system has a very high probability of ionization, and the cesium ion is massive, as required by Eq. (9).]

The three contact-ionization configurations that have received the most research attention are shown in Fig. 23. In the through-feed ionizer, neutral propellant atoms are ionized by contact with the hot metal surfaces as the atoms pass through the array of strips. In the reverse-feed ionizer, propellant atoms impinge on the ionizer surface where ionization occurs. The porous ionizer is similar to the through-feed ionizer, except that the flow through the last portion of the very small pores (say, 1-micron diameter) may occur by surface diffusion rather than by gas kinetic flow. In all three of these schemes, the hot ionizer surface is exposed to outer space through the exhaust aperture of the ion rocket engine, as shown in Fig. 21. Because of the high temperature of the contact-ionization surface, considerable radiant heat transfer occurs, and this power loss must be charged to the engine as an inefficiency. Since the power required to vaporize and ionize the propellant is very small in the contact-ionization engine, the power efficiency η is generally written

$$\eta = \frac{P_b}{P_b + P_{rad}} = \frac{1}{1 + (\sigma \epsilon T^4 F / j \Delta V)} \qquad (10)$$

where P_b is the ion beam power, P_{rad} is the radiant power loss, σ is the Stephan-Boltzmann constant, ϵ is the emissivity of the ionizer surface, and F is a radiant heat-transfer form factor.

From inspection of Eq. (10), it is apparent that the beam power $j\Delta V$ must be greater than the radiant power loss if contact-ionization ion rockets (with

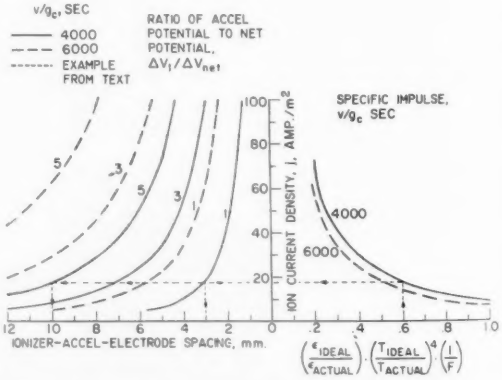

Fig. 24. Accelerator spacings required for contact-ionization ion rocket engine performance of 0.1-lb. thrust with 30-kw. power input.

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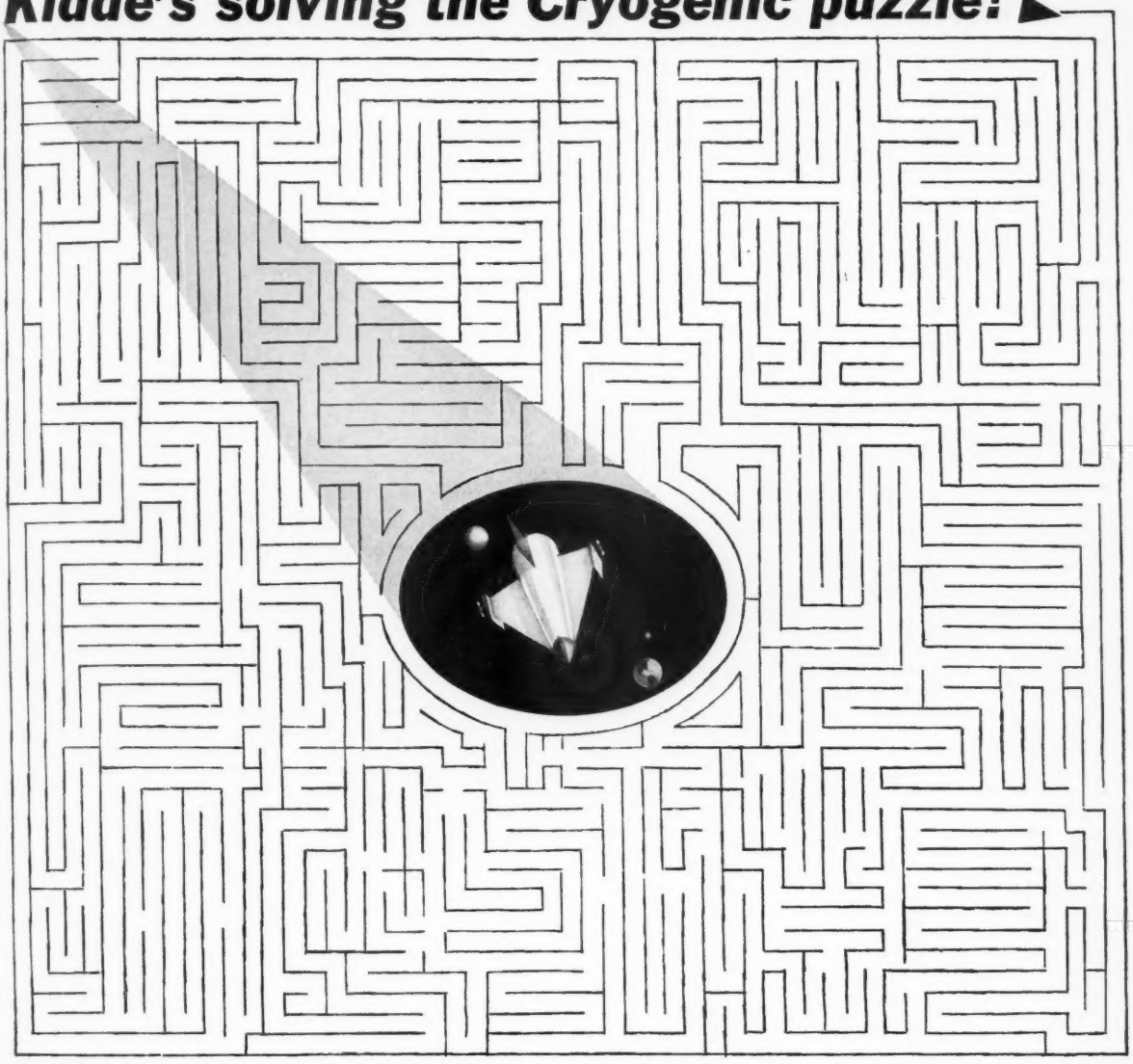

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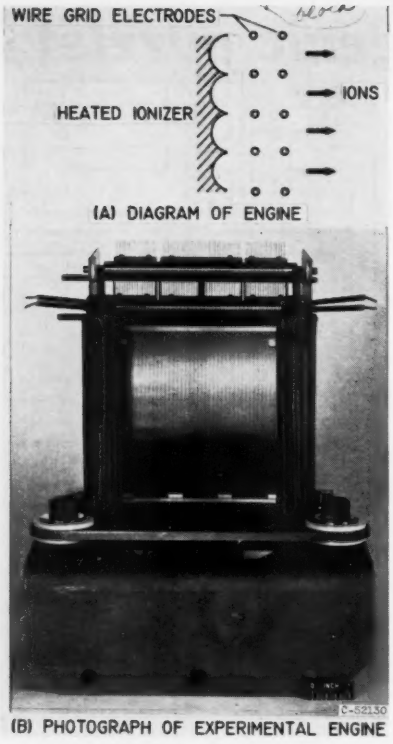

Fig. 25. Grid-electrode ion rocket engine.[23]

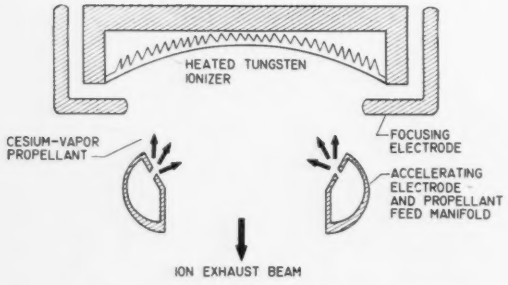

Fig. 26. Reverse-feed ion rocket engine.[33]

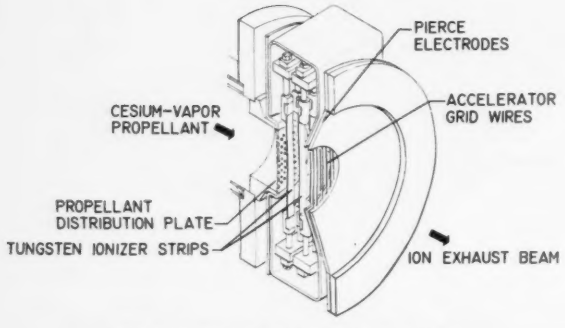

Fig. 27. Through-feed ion rocket engine.[33]

ionizers such as those shown in Fig. 23) are to be efficient. Since the accelerating potential is proportional to the square of the exhaust velocity as shown in Eq. (7), the current density j must be high in order to obtain good power efficiency for the lower range of specific impulse. To have high current density, the accelerator length must be short, as shown by Eq. (8). An alternative to short accelerator length is offered by the accelerate-decelerate system, wherein the ions are first accelerated to high velocity by the first set of electrodes shown in Fig. 21, and then decelerated by the second set of electrodes to provide the proper specific impulse for the space mission. Since the current density is primarily limited by the ion charge density at the ionizer, the "accel-decel" system essentially increases the current density by increasing the ΔV in Eq. (6), where ΔV is now the potential difference between the ionizer and the first set of electrodes and L is the spacing between these two components.

A comparison between the accel-only and the accel-decel systems is shown in Fig. 24 for a particular set of mission requirements. It is assumed that 30 kw. of electric power is available and that a thrust of 0.1 lb. is desired at two values of specific impulse, 4,000 and 6,000 sec. (which corresponds to power efficiencies of 29 and 44 per cent, respectively). On the right of Fig. 24, ion current density is plotted against the product of ratios, which essentially express the ratio of ideal to actual heat loss. On the left, ion current density is plotted against the ionizer - accel-electrode spacing for various ratios of $\Delta V_1/\Delta V_{net}$, where ΔV_1 is the potential difference between the ionizer and the accel-electrode (first set in Fig. 21) and ΔV_{net} is the net accelerator potential between the ionizer and decel-electrode (second set of electrodes in Fig. 21). Fig. 24 is valid for the cesium-tungsten system; the Reynolds[31] expression for ionizer surface temperature was used, and it was assumed that the accelerator could be represented by the Child-Langmuir law.

For example, if the ionizing surface became contaminated so that the emissivity and surface temperature were both 10 per cent above the ideal values, and if the form factor were 1.0, then the abscissa value on the right of Fig. 24 would be 0.6, and the current density required at a specific impulse of 4,000 sec. would be 19 amp./m.^{2}. If an accel-only system were used, the accelerator length would have to be 3 mm. or less. If an accel-decel system were used with a $\Delta V_1/\Delta N_{net}$ of 5, the ionizer - accel-electrode spacing could be 1 cm. Although these accelerator spacings are small by usual manufacturing practice, experimental ion rocket engines having such dimensions have been fabricated and successfully operated. Another important observation from Fig. 24 is that, as specific impulse is increased, the accelerator spacing requirements are considerably relaxed.

Childs[23, 32] has shown theoretically that a grid-electrode ion rocket engine with accelerator electrode spacings of 1 mm. may have good performance at specific impulse values as low as 2,000 sec. A diagram

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of a grid-electrode configuration is shown in Fig. 25(a). The ionizer could be either the reverse-feed or porous type and is shaped to focus the ion trajectories through the electrode apertures. Theoretical analysis[32] indicates that, with $\Delta V_1/\Delta V_{net}$ greater than 4.0, power efficiencies of over 50 per cent at a specific impulse of 2,000 sec. may be possible with 1.0-mm. spacings between the 0.1-mm.-diam. electrodes and the ionizer. A reverse-feed version of an experimental engine with these spacings and electrode sizes is shown in Fig. 25(b) and is presently being tested at the Lewis Research Center.

Another example of a reverse-feed engine is shown in Fig. 26. Vapor cesium propellant is injected through slits in the hollow accelerating electrodes, impinges on the heated tungsten ionizer, and is accelerated rearward through the exhaust aperature. Lockwood[33] has reported a power efficiency of 50 per cent, a propellant utilization efficiency of 85 per cent, and less than 1 per cent ion interception by the electrodes, at a specific impulse of 16,000 sec. The propellant vapor leaving the injector slit is in free-molecular flow so that some of the propellant misses the ionizer surface because of the semirandom efflux pattern. This problem is under further analytical and experimental study.

A through-feed engine design is shown in Fig. 27. Cesium propellant vapor is distributed uniformly and impinges on the tungsten ionizer strips, is ionized, and is accelerated through Pierce electrodes. Because the accelerator aperature was larger than the accelerator length, accelerator grid wires were necessary to preserve the potential field required by the Pierce electrode design. Dangle[33] has reported a power efficiency of 30 per cent and a propellant utilization efficiency of 50 per cent at a specific impulse of 17,000 sec. Further experimental research with this engine concept is being done at Lewis Research Center.

The propellant flow approaching the ionizer in any of the three ionizer schemes shown in Fig. 23 is at such a low pressure that the molecular mean free path is of the same order as (or larger than) the size of the channel, slit, or pore. In the resulting near free-molecular flow, the neutral atoms travel in straight paths, mostly interrupted only by solid surfaces. To prevent serious loss of propellant, it appears that the through-feed ionizer must have a close spacing between the rows of strips, and the configuration will then be similar to the reverse-feed ionizer.

The choice of ionizer is then reduced to two—the reverse-feed and the porous ionizer. Very approximate analyses have indicated that the pore size in a porous ionizer should be 1 micron or less for maximum current density and minimum neutral loss. Small, porous tungsten blocks of the type used for electron emitters in electronic devices are available and have been operated at a number of laboratories as cesium ion emitters. However, accurate experimental measurements of the neutral atom loss from such porous ionizers have not been reported as yet. In addition, the control of pore size in the submicron range, the elimination of pore blockage, and the fabrication of porous tungsten pieces with a maximum number of pores per unit area have not been demonstrated as yet.

The reverse-feed ionizer scheme also has its problems. As mentioned previously, charge exchange between accelerating ions and neutral atoms can cause serious sputtering of accelerator electrodes. In the reverse-feed ionizer, neutral atoms must pass directly through the accelerating ion stream before reaching the ionizer surface so that charge exchange might appear to be a more serious problem with the reverse-feed ionizer than with the porous ionizer. More experimental and theoretical research is necessary before a definite choice can be made between these two ionizer schemes.

Most of the discussion in this section has been concerned with ionization and acceleration, and the term "engine" has been loosely applied to devices which are only ion accelerators, without the neutralizer necessary to the ion rocket engine. Much theoretical analysis and some basic experimental work have been done on the neutralization of the ion exhaust beam. Since the neutralized ion beam is a plasma, the complexities mentioned previously with regard to plasma rocket engines are present in the ion rocket engine neutralizer. Because of the complex nature of real plasma, theoretical analyses of ion beam neutralization contain many assumptions that invalidate their practical use. In a recent paper, Brewer[34] has reported that a small ion exhaust beam has been effectively neutralized under carefully controlled experimental conditions. Brewer's neutralizer consisted of electrodes with a particular electrode shape, determined empirically with an electrolytic analog having approximate simulation of space charge effects. The neutralization of larger, more powerful ion exhaust beams remains to be demonstrated.

Concluding Remarks

Experiment and theoretical analysis have shown definitely that the electric rocket engine is a practical device for high performance in space flight. Many research and development problems remain to be solved, but all have solutions in theory. Detailed mission analysis has shown that the nuclear rocket may be competitive with the electric rocket for probes and manned flights to the near planets. For satellite control and raising, lunar ferries, and deep space flight, the electric rocket appears to be clearly superior to the chemical rocket, and to the nuclear rocket in its present form. The development of lighter weight electric power plants will make such comparisons more extreme since the power-plant weight is a prime factor in limiting electric spacecraft performance.

The feasibility of practical space flight is generally accepted. The justification of space flight is not so clear cut in all cases. Strong economic justification certainly can be made for communications satellites and meteorological satellites. Scientifically speaking, space flight opens a whole new realm of investigation of the secrets of the universe. Manned space flight and

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the exploration of the solar system perhaps must be justified on more philosophical grounds. A little girl in Kassel, Germany, once asked the author why he worked on rockets and space flight. With the aid of an English-Deutsch dictionary, the following reply was laboriously made:

"Volk muss haben gross Musik, Büchen, und Kunst. Und Volk muss haben gross Abenteuer."

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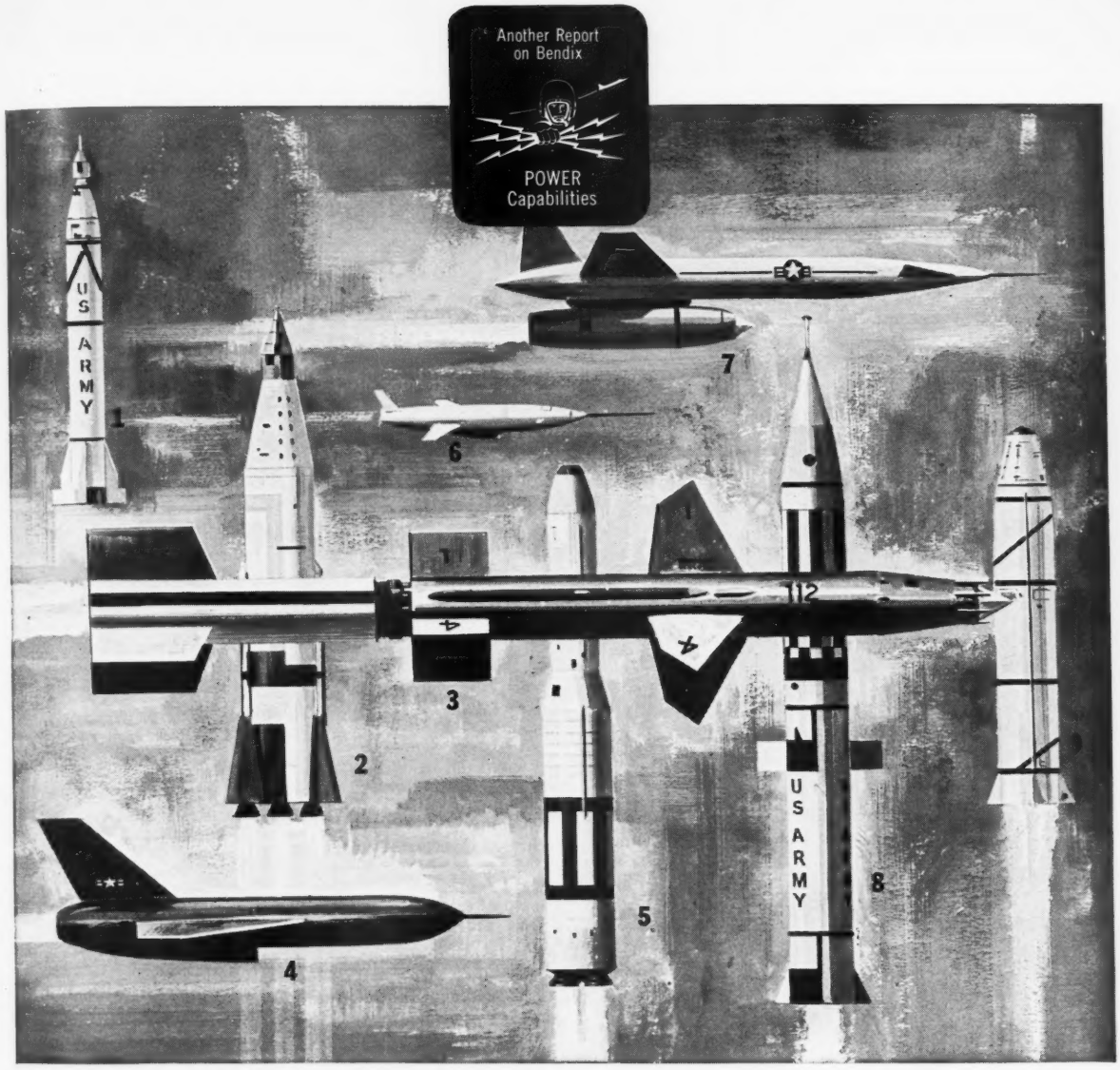
Simulated Flight Testing

(Continued from page 17)

The first attempt to control the pumping ratio was made by injecting water into the mixing tube. This method provided some control but only at the higher pumping pressure ratios (p_{10}/p_0). A second system consisted of a remotely controlled sleeve valve (Fig. 2). This valve bled outside air into the forward end of the mixing tube to reduce the simulated altitude. This provided system flexibility such that operation over the required altitude-Mach range was attainable. The pumping characteristics of this exhauster system are presented in Fig. 3a, along with the pumping characteristics of the model ejector of reference 2, for approximately the same secondary to primary nozzle weight



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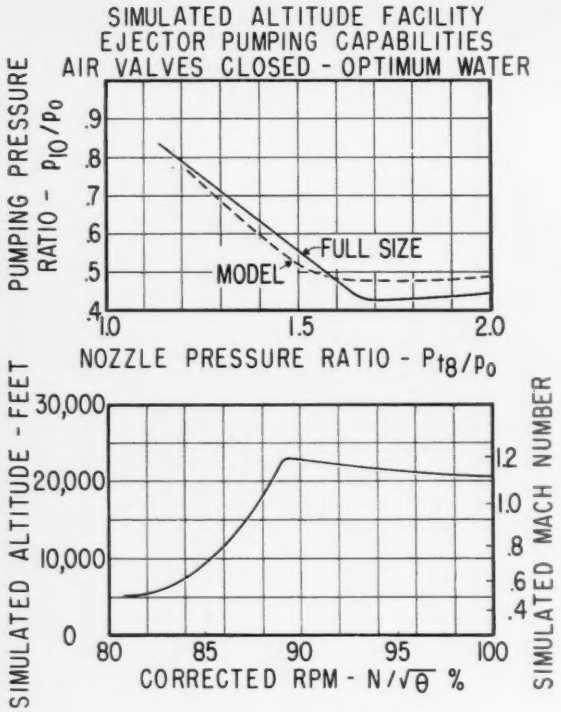

Figs. 3a (top) and 3b (bottom).

flow ratios (W_2/W_1). The full-scale ejector with a diffuser area ratio of 2.0 and the model ejector with a diffuser area ratio of 6.25 compare very well up to a primary nozzle pressure ratio of 1.55. Above 1.55, full-scale pumping slightly exceeds that of the model. Injection of water into the outer periphery of the exhaust jet lowered the pumping curve so that a higher altitude could be simulated at lower primary nozzle pressure ratios. This is probably due to increased stagnation pressure in the gas stream caused by cooling.[3] However, it appears the amount gained is determined by the ejector configuration and pumping parameters.

The capabilities of the exhauster with a J79-5 engine in terms of altitude and Mach number are shown in Fig. 3b. The maximum simulated altitude was 23,000 ft. with a Mach number of 1.2. This was attained at 91 per cent corrected r.p.m. without water injection. However, 20,000 ft. could be simulated with a Mach number of 1.1 over a range of corrected r.p.m. from 88.3 to 100 per cent.

By using the sleeve valve, a wide range of engine speed, simulated Mach numbers, and corresponding altitudes could be obtained. At a cruise Mach number of 0.92 (Alt. = 15,000 ft.), $N/\sqrt{\theta}$ was varied from 87.2 to 102.5 per cent.

Scale Thrust Measurement

Accurate gross thrust measurement of the cowled engine was a prime objective. This thrust was determined from strain gage, scale forces, and measured pressure-area and mass-velocity force terms. Because friction forces are difficult to determine, the two places where friction was most likely to be encountered were carefully designed to reduce friction to a minimum. These two places are the inlet and exhaust section of the nacelle where the independently supported nacelle mates with the ground-supported inlet bellmouth, and where the ground-supported exhaust mixing tube mates with the engine nozzle. The inlet joint consists of a frictionless rubber diaphragm seal, while the joint in the exhaust section consists of a variable air gap (approximately 1/8 in.) around the circumference as shown in Fig. 2. Four ball bearings are used as guides to keep the mixing tube from touching the plenum chamber.

The thrust suspension system consists of an overhead rectangular truss to which the pylon, nacelle, and engine are attached. The truss is suspended from the walls of the test cell by four short vertical links with bearings in each end. The measuring system is made up of two temperature-compensated strain gages which connect the two rear links to the test cell wall as shown in Fig. 2. Thus the truss is restrained from any fore or aft movement. The two strain gages form one leg of a Wheatstone bridge whose output is amplified and fed into a self-recording potentiometer. To calibrate the system, lead weights were hung on a cable-pulley arrangement that applied the weight force to the centerline of the engine while the potentiometer was recording. The lead weights were individually weighed, and a separate test was performed to determine the frictional forces incurred in the pulley bearings and the bending of the cables. The calibration provided a linear relation between potentiometer indication and weight applied, with a hysteresis of ±25 lbs. over a range of 0 to 5,200 lbs. The calibration was accomplished with the bellmouth, nozzle plenum, and mixing tube in place to account for any friction in the seal arrangement.

Scale force may be visualized to consist of the sum of inlet and exhaust forces. From the schematic diagram on Fig. 2, the forces may be stated as follows:

$$F_{inlet} = A_1p_1 + m_1V_1 + (A_m - A_{1a})p_o + [(A_{1a} - A_1)/2](p_o - p_{1a}) + (A_{1a} - A_1)p_{1a}$$

$$F_{exhaust} = A_9p_9 + m_9V_9 + (A_m - A_{10})p_o + (A_{10} - A_9)p_{10}$$

$$F_{scale} = F_{exhaust} - F_{inlet}$$

$$= A_9p_9 + m_9V_9 - A_{10}p_o + (A_{10} - A_9)p_{10} - A_1p_1 - m_1V_1 + A_{1a}p_o - [(A_{1a} - A_1)/2]\times(p_o - p_{1a}) - (A_{1a} - A_1)p_{1a}$$

Now engine gross thrust $(F_g) = m_9V_9 + A_9(p_9 - p_{10})$
So $F_g = F_{scale} + A_{10}p_o - A_{10}p_{10} + A_1p_1 + m_1V_1 - A_{1a}p_o + [(A_{1a} - A_1)/2](p_o - p_{1a}) + (A_{1a} - A_1)p_{1a}$

Thus by measuring scale force and pressure-area and mass-velocity forces as indicated in the preceding equation, the engine gross thrust may be determined. In order to determine accurately some of the terms, it was necessary to integrate measured pressures over the areas involved.

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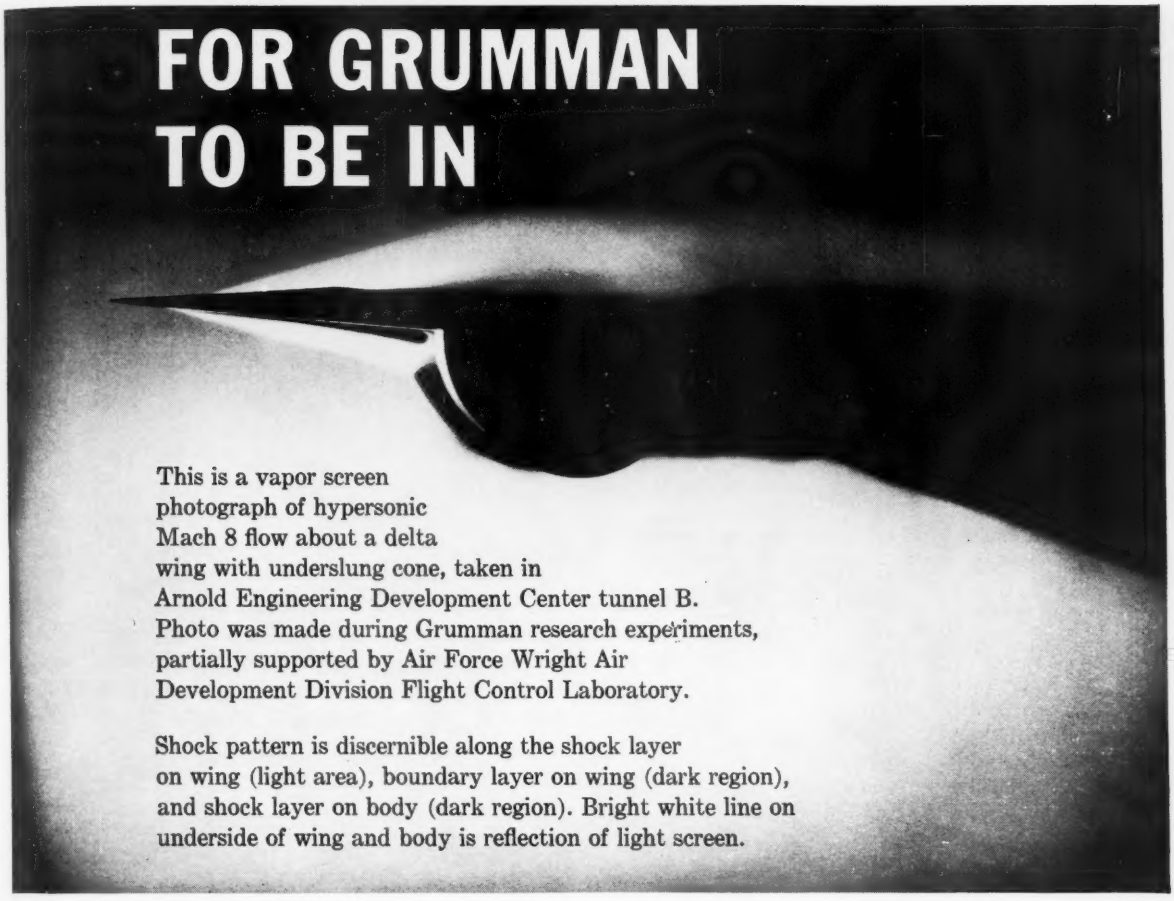

This is a vapor screen photograph of hypersonic Mach 8 flow about a delta wing with underslung cone, taken in Arnold Engineering Development Center tunnel B. Photo was made during Grumman research experiments, partially supported by Air Force Wright Air Development Division Flight Control Laboratory.

Shock pattern is discernible along the shock layer on wing (light area), boundary layer on wing (dark region), and shock layer on body (dark region). Bright white line on underside of wing and body is reflection of light screen.

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Conclusion

The method outlined here is useful in calibrating thrust instrumentation. Instrumentation thus calibrated was actually used to obtain thrust on a Convair B-58 and contributed substantially to the selection of a procedure to be used to obtain the accepted values of thrust, drag, specific fuel consumption, and other important performance parameters. Additional data can be obtained with the simulated altitude facility—for example, information was obtained on (1) the effects of primary nozzle area on specific fuel consumption, (2) the amount of secondary and primary engine airflow, and (3) the thrust loss due to main-stream swirl.

The procedure is capable of being expanded as to both the kind of tests run and the altitude-Mach number obtained. For example, hot-day or high-altitude take-off power can be run. Additional pumping by engines other than the engine being tested could add to the facility Mach-altitude capabilities.

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Maneuvering Space Vehicles

(Continued from page 23)

Modular Space Ferry

The basic ORV described provides considerable flexibility for selection of mission and payload. In addition, ORV has the highly desirable characteristic of being readily adaptable and expandable in the framework of a modular concept. The four basic modules considered are terminally guided orbital re-entry vehicle (ORV), parachute landing system (two sizes, depending on recovered weight, physically interchangeable), supplemental payload vehicle, and space maneuver stage.

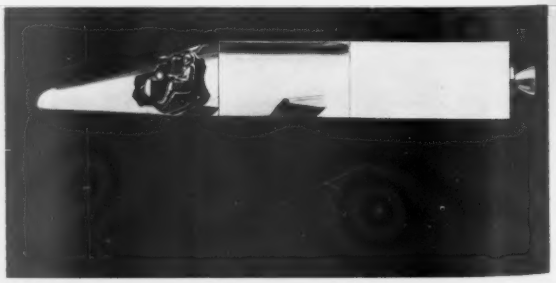
Possible combinations of these four modules for six different vehicle models are shown in Table 3. In Model 1, the ORV flies alone and is recoverable. In Model 2, the ORV is recoverable and the supplemental payload unit is not recoverable. In Model 3, the ORV and supplemental payload unit are both recoverable. In Model 4, the ORV is recoverable and flies with a space maneuver stage vehicle, as for rendezvous. In Model 5, the ORV is recoverable, the supplemental payload unit is not, and both are used with a space maneuver vehicle. In Model 6, both the ORV and the supplemental payload unit are recoverable, and both are used with the space maneuver vehicle. The flexibility of such a concept is evident, as is the advantage of initiating development of the basic modules one at a time, as required for continuously developing missions.

Table 3. Modular Concept

VEHICLE MODEL	BASIC MODULES			
	TERMINALLY GUIDED ORBITAL RE-ENTRY VEHICLE	PARACHUTE LANDING SYSTEM	SUPPLEMENTAL PAYLOAD VEHICLE	SPACE MANEUVER STAGE
1. TERMINALLY GUIDED VEHICLE RECOVERABLE	X	X		
2. TERMINALLY GUIDED VEHICLE RECOVERABLE; SUPPLEMENTAL PAYLOAD UNIT NON-RECOVERABLE	X	X	X	
3. TERMINALLY GUIDED VEHICLE AND SUPPLEMENTAL PAYLOAD UNIT RECOVERABLE	X	X	X	
4. TERMINALLY GUIDED VEHICLE RECOVERABLE; SPACE MANEUVER VEHICLE NON-RECOVERABLE	X	X		X
5. TERMINALLY GUIDED VEHICLE RECOVERABLE; SUPPLEMENTAL PAYLOAD UNIT NON-RECOVERABLE; SPACE MANEUVER VEHICLE NON-RECOVERABLE	X	X	X	X
6. TERMINALLY GUIDED VEHICLE AND SUPPLEMENTAL PAYLOAD UNIT RECOVERABLE; SPACE MANEUVER VEHICLE NON-RECOVERABLE	X	X	X	X

Those vehicle models containing the space maneuver module have all the fundamental elements required for a *modular space ferry* (see Fig. 15). In this modular space ferry concept, the cargo sections can be built to interchange with special sections for a specific mission requirement such as personnel transfer. On a given mission, if the cargo section is not needed for the return portion of that mission, this section could be detached and left at the space station for loading and pickup by another ferry vehicle. It may be possible to develop a space freight train concept by utilizing some unmanned units to be later collected and delivered by a manned vehicle. It should be noted that the crew module shown is only a possible configuration. The position of the crew might have to be varied for re-entry in order to reduce the g loading on the bodies in the event of a control failure and ballistic, rather than glide, return. For this vehicle it may also be necessary to provide an external fairing for aerodynamic stability of the total vehicle with booster during boost from the earth's surface.

Fig. 15. Modular ferry.



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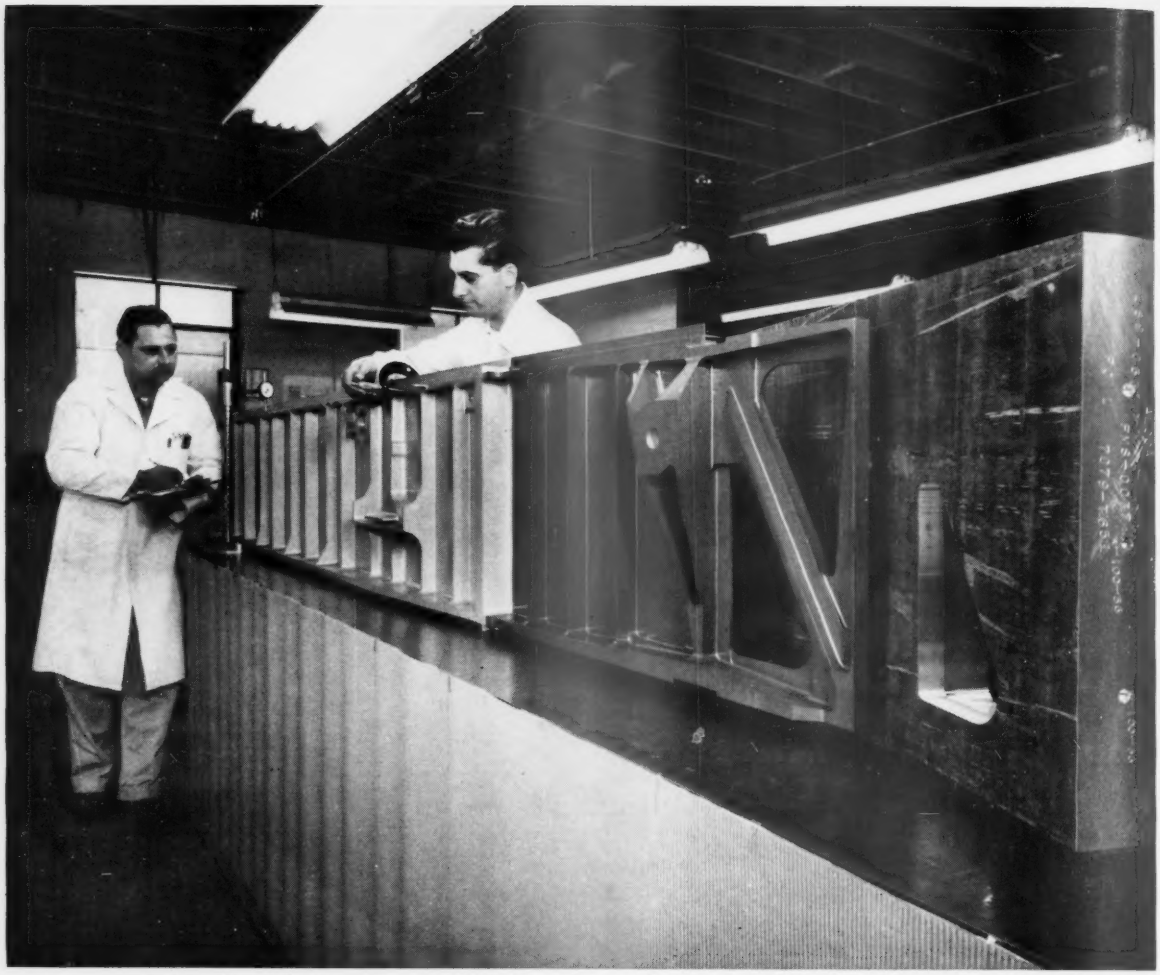

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Conclusions

The parametric design and performance studies presented show that many maneuverable space vehicle missions can be performed with present or near-future hardware state of the art. Other missions require extensive hardware development, particularly in the area of high specific impulse propulsion.

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✦ ✦ ✦

Anti-Skid System (Continued from page 27)

amplifier B is added. This amplifier is designed with a relatively large time-constant so that it is sensitive only to the component ω_0 of wheel angular velocity, and acts to maintain the generator excitation voltage K at such a value that $K\omega_0$ is constant. The accelerator output is now independent of ω_0 and the generator output is inversely proportional to ω_0, in consequence of which the overall system operation is as before, except that the general level of signals is now independent of changes in ω_0.

Time-Constants and Dither Period

In a typical landing run, the wheel angular velocity is reduced from its maximum value to zero in a time of the order of 40 sec. Thus the time constant R_1C_1 in Fig. 4, or its equivalent in amplifier B in Fig. 6, may well be as large as a few seconds.

The value of k in Eq. (7) should be such that the effective time-constant of the braking system transients is small compared to R_1C_1. Hence this time-constant may well be some substantial fraction of a second.

The dither period should be small compared to the effective time-constant of the braking system transients

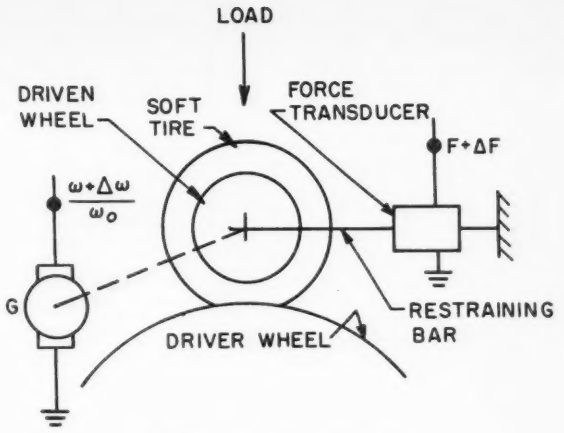

Fig. 7. Breadboard arrangement.

so that the latter are blocked by elements R_2, C_2 and R_3, C_3 in Fig. 4 without unduly attenuating the a.c. components resulting from dither. A small dither period also permits amplifier A to drive motor M to its equilibrium position in a time very short compared to the transient time-constant, as has been assumed in the previous analysis; an undue increase in motor positioning time may possibly lead to instability of the system. Further, the dither period should not be less than the time-constant of the response of the wheel angular velocity to changes in brake torque; this time-constant increases with the mass moment of inertia of the wheel and with increasing aircraft speed, and can also be shown to increase with the reciprocal of the slope of the curve of F vs. S. However, the dither period need not necessarily be large compared to this time-constant since it can be shown that ΔF and $\Delta\omega$ in Eq. (2) are equally attenuated and phase-shifted, with respect to brake-torque fluctuations, as a result of wheel inertia. These various considerations are expected to lead to a dither period of several cycles per second.

Additional Dither Requirements

The force producing the dither in valve V should be great enough to produce appreciable dither in spite of friction, play, and elasticity in the valve and connected parts. However, the magnitude of dither need not be held to close limits since it is not used as data in the system. The dither may be highly nonsinusoidal since provision can readily be made in Fig. 4 for filtering out higher harmonics.

The dither frequency should of course not be such as to induce significant vibrational resonances in the aircraft structure.

Recommended Future Program

Prior to installing the system in an actual aircraft, it will be desirable to build it and check it roughly on a breadboard. A suitable experimental arrangement for this purpose is shown in Fig. 7. The *driver* wheel is turned by an engine (not shown) whose angular velocity, which may be changed continuously to sim-

ulate a landing run, is essentially unaffected by disturbances of the *driven* wheel. The latter is subjected to a vertical load and has a soft tire of such characteristics that, operating against the surface of the driver wheel, it approximates the behavior of an aircraft wheel on a runway. The brakes (not shown) are applied to the driven wheel and are subjected to a suitable dither. Generator G, mounted on the driven wheel and excited in the manner of Fig. 6, provides the output $(\omega + \Delta\omega)/\omega_0$. The force transducer (which may be a strain gage) is mounted on the restraining bar and provides the output $F + \Delta F$.

The breadboard of the rest of the system follows conventional instrumentation practice. The normal force between the wheels, as well as the surface conditions, may be modified to simulate different conditions of airplane loading and ground.

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Space Reconnaissance (Continued from page 31)

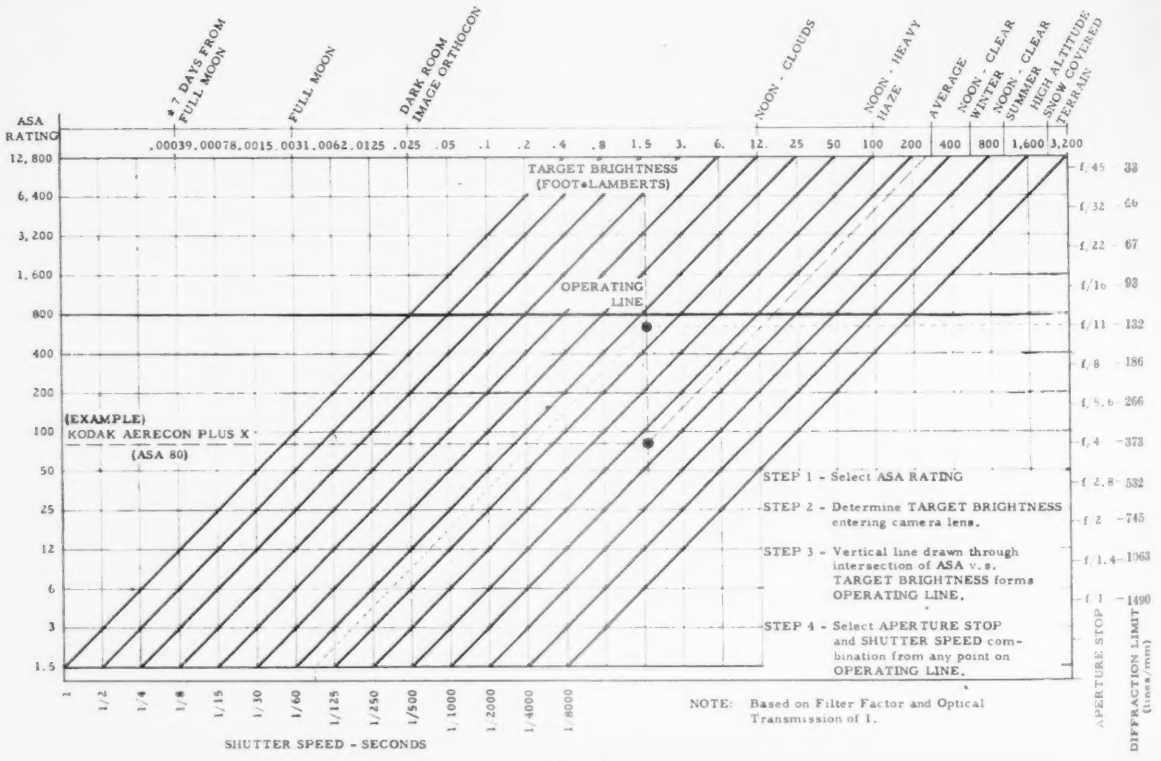
Aperture and Equipment Size

In order to take a photograph from high altitude on a clear day with film such as Plus X, a lens system of about f/11 aperture ratio and an exposure time of about 1/100 sec. are required. As the focal lengths increase for the same aperture ratio, the diameter of the lens increases. Thus the volume limitation and weight limitation of the vehicle enters the problem. There are a number of trade-offs possible between aperture ratio, shutter speed, and film properties which yield a reasonable system.

Parameter Curve

The parameter curve (Graph C) shows some of the variables. It is important to note the diffraction limit of the lens system which shows that, as the lens is stopped down, the capability of the system is reduced.

There are films being developed with adequate resolving power and ASA rating to cover the lens systems now available. The state of the art in film is in step with the field so that film is not a limiting factor.



Graph C.

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April, 1960: TIROS I. The sophisticated satellite, including its structural design as well as the electronic systems, and its ground stations were developed and built for NASA by AED under the technical direction of the U.S. Army Signal Corps. It accomplished its mission in meteorological observation, sending down over 20,000 TV pictures of earth and its cloud cover.

August, 1960: Project ECHO. The only electronic equipment on this 100-foot balloon, launched by NASA to prove the feasibility of passive communications satellites, are two "dinner plate" beacon transmitters 10 inches across by ⅜ inch thick, including storage batteries and solar cells. These units, designed to permit beacon tracking of the satellite, weigh only 11 ounces apiece and were developed and built by AED.

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Conclusion

Radar seems capable of obtaining some geophysical data on surface composition and structure. Further development along these lines is needed.

Telemetering of data, either TV or photo-transmission back to earth where actual data recovery is not possible, requires a great deal of development effort. The 200-lb. transmitter sending 10^7 bits per sec. from the moon or 5,000 bits per sec. from Venus, and requiring a 60-ft. antenna on earth, leave much to be desired.[6]

There is photographic system technology in existence with sufficient know-how to design systems with focal length and resolution to satisfy the most exacting requirement of space reconnaissance for orbital altitudes up to a few hundred miles. The physics of the situation is quite clear as to the angular resolution requirement of ground targets. The photochemistry of photography and the elements of radar and infrared are well understood in practice. Application of this available knowledge in space programs has been slow but steady. Recent photographs and TV pictures of varying resolution have been obtained from space vehicles. These photographs are not as good as those obtained from the V-2 shots in 1950 (see the *National Geographic*, October, 1950). The techniques of long focal length cameras of reasonable (attainable) resolution are available. The optical technology has progressed to approach the diffraction limited lens. Film properties and processing are being upgraded so 100 l./mm. performance is being realized. Infrared and radar are wavelength limited but, when used with photography, give good capability of reconnaissance. Each situation, air or orbit, has a unique optimum solution of reconnaissance equipment.

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PERIODICALS AND REPORTS..... 66
INTERNATIONAL AERONAUTICAL ABSTRACTS 75
BOOKS..... 103

Subject Index to Periodicals & Reports

Acoustics, Sound, Noise..... 66
Aerodynamics, Fluid Mechanics
  Aerothermochemistry, Dissociation, Ablation..... 66
  Aerothermodynamics..... 66
  Boundary Layer..... 66
  Flow of Fluids..... 66
  Internal Flow..... 70
  Stability & Control..... 70
  Wings & Airfoils..... 70
Aeroelasticity..... 70
Aeronautics, General..... 70
Air Transportation..... 70
Airplanes
  Cockpits, Canopies, Windshields..... 70
  Description..... 70
  Landing, Landing Loads..... 71
  Operating Characteristics, Economics. 71
  Piloting..... 71
Airports..... 71
  Heliports..... 71
Aviation & Space Medicine..... 71
  Human Engineering..... 72
Chemistry..... 72
Computers..... 72
Control Theory..... 72
Documentation..... 72
Education & Training..... 72
Electronics..... 72
  Amplifiers..... 74
  Antennas, Radomes..... 74
  Circuits & Components..... 74
  Communications..... 74
  Dielectrics..... 74
  Magnetic Devices..... 74
  Networks, Filters..... 74
  Power Supplies..... 74
  Radar..... 74
  Semiconductors..... 74
  Telemetry..... 74
  Transmission Lines..... 91
  Wave Theory..... 91
Equipment..... 92
  Electric..... 92
  Hydraulic & Pneumatic..... 92
Fuels & Lubricants..... 92
Gliders..... 92
Instruments..... 92
  Accelerometers..... 92
  Flight Instruments..... 92
  Flow Measuring Devices..... 92
  Gyroscopes..... 92
  Pressure Measuring Devices..... 92
  Stress & Strain Measuring Devices.... 92
Laws & Regulations..... 92
Machine Elements
  Bearings..... 92
  Gears & Cams..... 92
Maintenance..... 92
Materials..... 92
  Ceramics & Ceramals..... 92
  Corrosion & Protective Coatings..... 92
  High-Temperature..... 94
  Metals & Alloys..... 94
  Metals & Alloys, Nonferrous..... 94
  Nonmetallic Materials..... 94
  Testing Methods..... 94
Mathematics
  Differential Equations..... 94
  Functions & Operators..... 95
  Matrices..... 95
  Numerical Analysis..... 95
  Physical Applications..... 95
  Probability, Statistics..... 95
  Theory of Numbers..... 95
  Topology..... 96
Mechanics..... 96
Meteorology..... 96
  Atmospheric Structure & Physics..... 96
  Upper Air Research..... 96
Missile, Rocket, & Space Technology... 96
  Ballistics, Re-Entry..... 97
  Guidance, Control, Stability..... 97
  Spacecraft..... 97
Navigation..... 97
  Electronic Aids..... 98
  Traffic Control..... 98
Nuclear Energy..... 98
Photography..... 98
Physics..... 98
  Astrophysics..... 98
  Geophysics..... 98
  Optics..... 98
Power Plants..... 98
  Jet & Turbine..... 99
  Rocket..... 99
Production..... 99
  Metalworking..... 99
Propellers..... 99
Reliability..... 100
Research, Research Facilities..... 100
  Flight Testing..... 100
  Wind Tunnels..... 100
Rotating Wing Aircraft, Helicopters..... 100
Safety..... 100
Structures..... 100
  Bars & Rods..... 100
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  Elasticity & Plasticity..... 100
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  Testing Methods..... 101
  Thermal Stress..... 101
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Aerothermochemistry, Dissociation, Ablation

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General Research in Flight Sciences—Fluid Mechanics. VI—Hypersonic Flow Around Bodies of Revolution Which Are Generated by Conic Sections. M. Vinokur. (*6th Midwest. Conf. Fluid Mech., Austin, Sept. 9–11, 1959.*) *Lockheed Aircraft Missiles & Space Div., vol. I, Pt. I, TR LMSD-288139*, Jan., 1959–Jan., 1960. 27 pp. 22 refs. Presentation of two approximate analytic solutions for the inviscid supersonic blunt-body problem. In one, the shock wave is assumed to be locally confocal with the body, and in the other, the shock curvature is assumed constant near the axis. Both solutions reduce to that of Lighthill in the case of the sphere.

Note on the Assessment of Flow Disturbances at a Blunt Body Traveling at Supersonic Speeds Owing to Flow Disturbances in Free Stream. M. V. Morkovin. (*ASME Summer Conf., Univ. Park, Penn., June 20–22, 1960, Paper 60-APM-10.*) *ASME Trans., Ser. E - AM*, June, 1960, pp. 223–229. 13 refs. Presentation of an analysis of the magnitude of flow disturbances which affect conditions on the blunt nose of a body moving at supersonic speeds, showing that pressure fluctuations generated by interactions of entropy-temperature disturbances with the normal shock may be considerable at high Mach numbers, but that the reflections of such pressure waves between the body and the shock wave definitely cannot lead to high resonant amplifications.

On Bodies of Minimum Wave Drag. V. N. Zhigulev and Iu. L. Zhilin. (*Prikl. Mat. i Mekh.*, Nov.-Dec., 1959, pp. 1019–1029.) *PMM—Appl. Math. & Mech.*, No. 6, 1959, pp. 1462–1475. Translation. Investigation of certain variational problems for a body that slightly disturbs a supersonic stream. It is found possible, in the general case, to separate the problem of determining the drag from that of determining the minimum drag body itself. As an example, relations are found connecting the volume of the body with the values of the perturbation velocity potential on the characteristic surfaces enclosing the body.

Flow of a Viscous Heat-Conducting Gas at High Supersonic Speeds About a Cone. V. V. Lunev. (*Prikl. Mat. i Mekh.*, Nov.-Dec., 1959, pp. 1006–1018.) *PMM—Appl. Math. & Mech.*, No. 6, 1959, pp. 1444–1461. 12 refs. Translation. Analysis of the case of weak interaction between the viscous and nonviscous regions—i.e., only the region of flow sufficiently far removed from the nose of the cone is considered.

Dimensionless Parameters for Viscous Similarity. A. G. Hammitt. *J. Aerospace Sci.*, Sept., 1960, p. 720. USAF-supported discussion of two-parameter representations of viscosity as a function of temperature, and application to the case of the hypersonic flow about a blunt body.

Approximate Free Molecule Aerodynamic Characteristics. D. M. Schrello. (*North Am. Av. Rep. NA 59H-345*, Aug. 17, 1959.) *ARS J.*, Aug., 1960, pp. 765–767. Abridged. Derivation of expressions for the free molecule lift, drag, and static pitching moment of an arbitrary body of revolution under the restriction that the average normal component of the molecular speed ratio over the exposed body surface be greater than or equal to unity.

O Raschete Obtekaniia Osesimmetrichnykh Tel s Otoshedshei Udarnoi Volnoi na Elektronnoi Schetnoi Mashine. O. M. Belotserkovskii. *Prikl. Mat. i Mekh.*, May-June, 1960, pp. 511–517. In Russian. Development of a method for calculating, by means of an electronic computer, the flow about axisymmetric bodies with a detached shock wave. Results are presented for certain simple bodies such as ellipsoids, spheres, and discs.

A Comparison of Blunt-Body Flow-Field Results. H. W. Ridyard. *J. Aerospace Sci.*, Oct., 1960, pp. 789–791. USAF-supported comparison of the Van Dyke forward-integration method and the method of characteristics for blunt-body solutions downstream of the supersonic region.

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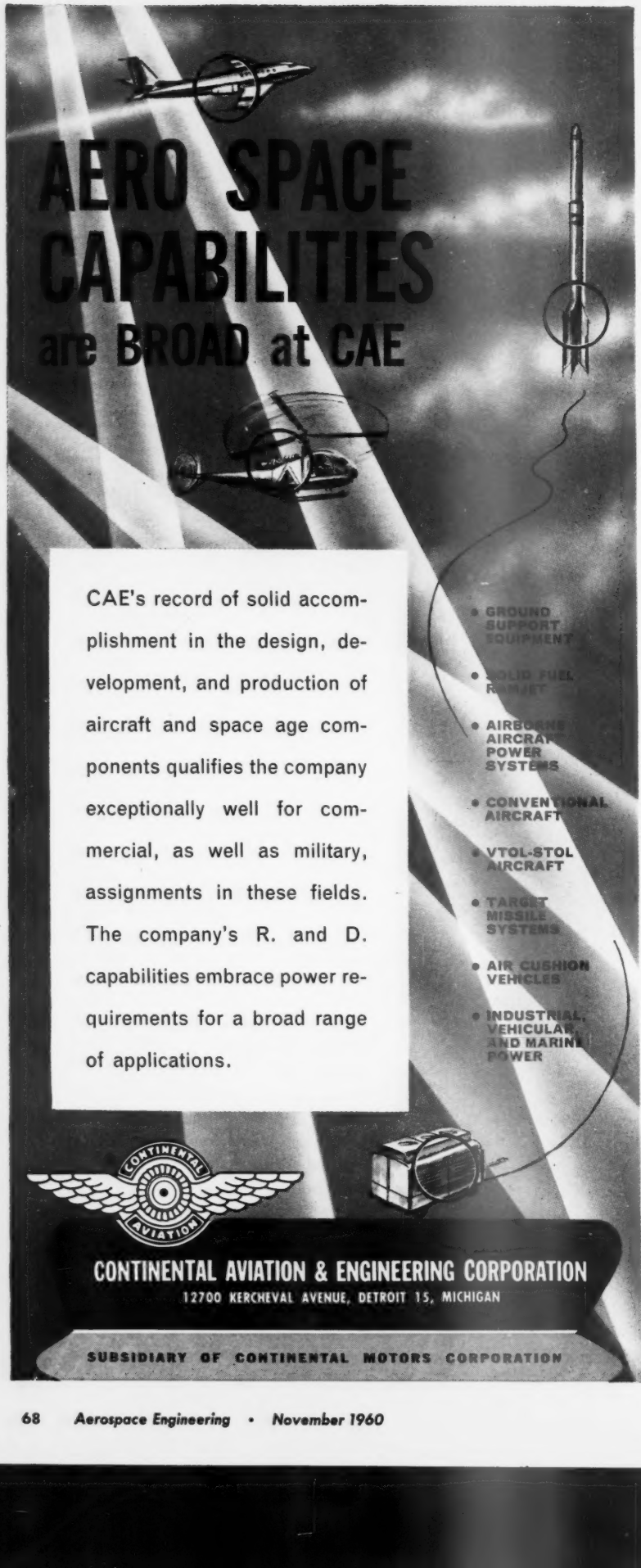
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K Teorii Giperzvukovykh Techenii Gaza so Skachkami Uplotneniia Stepennoi Formy. V. V. Sychev. *Prikl. Mat. i Mekh.*, May-June, 1960, pp. 518–523. In Russian. Study of plane and axisymmetric flows of gas with compressibility jumps of great intensity. Based on the results for the high-entropy region of the flow adjacent to the surface of the body, it is shown that the use of exact solutions for corresponding nonstationary gas motion requires additional data on the thickness of the high-entropy layer. A method is shown for achieving this correction and for obtaining the shape of the body, incorporating the pressure distribution obtained on the basis of the small perturbation theory.

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On the Drag on a Rigid Sphere Moving in a Viscous Liquid Inside a Cylindrical Tube. Torsten Bohlin. *KTH Trans. 155*, 1960. 63 pp. Presentation of a more accurate drag formula and investigation of the influence of a superimposed flow of the liquid through the tube. The drag is computed by solving the linear parts of the Navier-Stokes equations.

Exact Solutions of the Magnetohydrodynamic Equations. W. E. Williams. *J. Fluid Mech.*, July, 1960, pp. 452–464. 15 refs. Presentation of exact one-dimensional solutions for an incompressible fluid. It is shown that one class of plane wave solutions of the linearized equations is also a possible class of solutions of the general equations including the effect of displacement current.

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General Research in Flight Sciences—Fluid Mechanics. IV—Steady Two-Dimensional Flow with a Transverse Magnetic Field. M. Mitchner. (The Magnetodynamics of Conducting Fluids, ed. Daniel Bershader, Stanford U. Press, 1959, pp. 60–89.) *Lockheed Aircraft Missiles & Space Div., vol. I, Pt. II, TR LMSD-288139*, Jan., 1959–Jan., 1960. 22 pp. Development of equations for the steady, two-dimensional, isentropic and irrotational flow of a perfect electrically conducting fluid in a transverse magnetic field.

Unsteady Incompressible Couette Flow in a Uniform Transverse Magnetic Field. C. C. Mei. *Appl. Sci. Res., Sect. A*, No. 4, 1960, pp. 275–284. Presentation of a general solution in a series form, obtained by means of a finite Fourier transform, of the unsteady plane Couette flow of an incompressible, viscous, and infinitely conducting fluid in a uniformly applied transverse magnetic field. Explicit solutions for two special cases are given.

Surface Disturbances in Magnetohydrodynamics. S. I. Syrovatskiy. (*AN SSSR Trudy Fiz. Inst.*, vol. 8, 1956, pp. 13–64.) *U. S., NASA TT F-23*, May, 1960. 45 pp. 25 refs. Translation. OTS, $1.25. Investigation of characteristics of surface disturbances on magnetohydrodynamics, including unusual "transient" disturbances. Primary consideration, however, is given to the problem of stability of tangential disturbances. A possible explanation is offered of stable and sharply defined streams in the form of jets and bands which are observed in the atmosphere of the sun and which are difficult to explain in terms of ordinary hydrodynamics.

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Hypersonic Flow Past a Body in Magneto-Hydrodynamics. M. D. Ladyzhenskii. (*Prikl. Mat. i Mekh.*, Nov.-Dec., 1959, pp. 993–1005.) *PMM—Appl. Math. & Mech.*, No. 6, 1959, pp. 1427–1443. Translation. Analysis of the effect of a strong imposed magnetic field on the general flow picture, considered for the case of hypersonic flow past a cone- or wedge-shaped body when the magnetic field intensity vector is directed perpendicular to the surface of the body. It is shown that, under certain conditions, the flow may separate from the wall. This case is also investigated.

Magnetohydrodynamic Effects Upon Heat Transfer for Laminar Flow Across a Flat Plate. R. D. Cess. (*ASME-AIChE Heat Transfer Conf., Storrs, Conn., Aug. 9–12, 1959, Paper 59-HT-14.*) *ASME Trans., Ser. C - HT*, May, 1960, pp. 87–93. 13 refs. Presentation of an analysis of forced-convection heat transfer for laminar flow of electrically conducting fluids across a flat plate, considered for a magnetic field of constant inductance acting normal to the free stream velocity and fixed relative to the plate. The boundary condition on the surface of the

plate is taken to be either a constant temperature or constant heat flux, and solutions are presented for the following cases: (a) fluids having a Prandtl number of unity for which both Joule heating and frictional heating are accounted for; (b) fluids having moderate and large Prandtl numbers for negligible Joule and frictional heating; and (c) fluids having low Prandtl numbers for negligible frictional heating.

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On Steady Axially Symmetric Solutions of the Idealized Hydromagnetic Equations for a Compressible Gas in Which There is no Diffusion of Vorticity, Heat, or Current. T. V. Davies. *Quart. J. Mech. & Appl. Math.*, May, 1960, pp. 169–183.

Magnetohydrodynamic Cavities. Bernard Steginsky. *ARS J.*, July, 1960, pp. 642, 643. Discussion of the cavities that arise in connection with the flow of a perfectly conducting fluid past a magnetic field source. Examination of the dependence of the final steady-state configuration on the initial conditions in two cases reveals incompatibilities which may arise in the physical interpretation of the problem if a proper "model" is not specified.

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The Superfast Pinch Experiment. Vernal Josephson. *Space Tech. Lab. PRL TR 59-0000-09880*, Nov. 2, 1959. 26 pp. USAF-supported discussion of the design features and operational problems encountered in an assembly designed to accelerate deuterons by means of a radially converging magnetic piston.

Transverse Pinch Oscillations. B. D. Fried. *Space Tech. Lab. PRL STL TN 60-0000-09059*, Mar. 24, 1960. 8 pp. USAF-supported analysis showing that the oscillations or "bouncing" of a transverse pinch, like those observed by Wuerker, are predicted by a simple model in which no trapped magnetic field is assumed.

Some Remarks on the Structure of a Normal Magneto-Hydrodynamic Shock Wave. A. G. Kulikovskii and G. A. Luibimov. (*Prikl. Mat. i Mekh.*, Nov.-Dec., 1959, pp. 1146, 1147.) *PMM—Appl. Math. & Mech.*, No. 6, 1959, pp. 1644–1647. Translation. Study taking into account the effects of thermal and electrical conductivity, but not of viscosity.

Effect of Conductivity Anisotropy in a Magnetic Field on the Structure of a Shock Wave in Magnetogasdynamics. S. A. Kaplan. (*Zhurnal Teoret. i Exper. Fiz.*, Jan., 1960, pp. 252, 253.) *Sov. Phys. - JETP*, July, 1960, p. 183. Translation.

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Plasma Turbulence. L. S. G. Kovasznay. *Space Tech. Lab. PRL STL TR 60-0000-AE038*, Feb. 17, 1960. 22 pp. 10 refs. USAF-supported study of solenoidal turbulent velocity fluctuations that assumes the validity of the simple magnetohydrodynamic equations. Using the Reynolds type of approach, equations are obtained for the mean flows and mean electromagnetic field, and also for the turbulent kinetic energy and turbulent magnetic energy of the fluctuating fields.

The Radiation Resistance of an Elementary Dipole in Anisotropic Plasmas. Herwig Kogelnik. *Oxford U. Eng. Lab. TN 3 (AFOSR TN 60-49)*, 1960. 14 pp. 13 refs.

Electromagnetic Radiation from an Ionized Hydrogen Plasma. S. M. Berman. *Space Tech. Lab. PRL 9-27*, Sept. 24, 1959. 25 pp. 15 refs. Study of the radiant energy emitted by a hydrogen plasma in the temperature range from 0.7 to 9.0 ev due to the processes of recombination of electrons and protons to form hydrogen atoms, bound-bound transitions of excited hydrogen atoms, and bremsstrahlung of free electrons.

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Effect of Transverse Magnetic Field on the Flow Due to an Oscillating Flat Plate. II. Tsunehiko Kakutani. *Phys. Soc. Japan J.*, July, 1960, pp. 1316–1331. Presentation of exact solutions for arbitrary values of the Reynolds number, the magnetic Reynolds number, and the magnetic pressure number. Special cases corresponding to the limiting values of these parameters are discussed to clarify the hydromagnetic effect. The drag on the plate is calculated for both a nonconducting and a perfectly conducting plate.

A Study of Plasma Stability in Microwave Cavities by a Frequency-Shift Analog. R. A. Swanson. *Space Tech. Lab. PRL TR 59-0000-00812*, 1960. 12 pp. USAF-supported derivation of an equation which relates the pressure change at a perturbed microwave cavity boundary to the change in resonant frequency of the cavity. The equation is used to obtain information on the stability of plasma confined by microwave fields.

Non-Linear Effects on Electron-Plasma Oscillations. Masao Sumi. *Phys. Soc. Japan J.*, June, 1960, pp. 1086–1093. 16 refs. Discussion on the nonlinear effects in the excitation of electron plasma oscillations, considering a nonlinear term in the Boltzmann equation as a perturbation. The magnitudes of the fundamental components are estimated and the behavior of excited waves in the limit of large amplitude is described.

Blunt Body Viscous Layer with and Without a Magnetic Field. Hakuro Oguchi. (*Brown U. Div. Eng. Rep. USAF WADC TN 58-145*, Feb., 1960.) *Phys. Fluids*, July-Aug., 1960, pp. 567–580. 17 refs.

Influence of a Magnetic Field on Boundary Layer Stability. V. N. Arkhipov. (*AN SSSR Dokl.*, Dec. 1, 1959, pp. 751–753.) *Sov. Phys. - Dokl.*, May-June, 1960, pp. 1199–1201. Translation. Analysis of the stability of a parallel flow of viscous conducting incompressible gas with respect to small perturbations in the velocity and magnetic fields.

On the Linear Behavior of Large-Amplitude Magnetohydrodynamic Waves. J. Shmoys and E. Mishkin. *Phys. Fluids*, July-Aug., 1960, pp. 661, 662. Extension of Cowling's discussion of magnetohydrodynamic waves to include incompressible fluids with finite conductivity, showing that the resulting equations are linear irrespective of the amplitude and that the current, the a.c. magnetic field, and the electric field are all transverse.

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O Rasprostranenii Vozmushchenii v Ploskikh Magnitogidrodinamicheskikh Techeniiakh. M. N. Kogan. *Prikl. Mat. i Mekh.*, May-June, 1960, pp. 530–536. In Russian. Study of the propagation of turbulence from the turning points of flow lines. It is shown that shock waves can propagate from convex angular points; in concave angular points, however, the flow occurs in waves of the Prandtl-Meyer type. The analysis is extended to the study of flow about bodies in the case of small angle of inclination of the magnetic field in relation to the velocity of the incident flow.

On Certain Properties of Hydromagnetic Shocks. W. B. Erickson and J. Bazer. (*Am. Phys. Soc. Symposium on Plasma Phys., Monterey, Dec. 4, 1959.*) *Phys. Fluids*, July-Aug., 1960, pp. 631–640. Presentation of proofs of four basic properties of stationary, planar, nonrelativistic hydromagnetic shocks.

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Separation of Magnetic Driving and Ohmic Heating. J. R. Banister. *Phys. Fluids*, July-Aug., 1960, pp. 648–655. Presentation of a theoretical method which is potentially useful for studying plasma conductivity and equation of state. The experiment entails the passing of brief unidirectional current discharges through nitrogen in the presence of a transverse uniform magnetic field.

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Plasma Viscosity in a Magnetic Field. A. N. Kaufman. *Phys. Fluids*, July-Aug., 1960, pp. 610–616. Analysis of the viscosity of a fully ionized plasma in a magnetic field, taking into consideration particle orbits and the solution of a simplified Boltzmann equation. These semiquantitative methods are studied in order to clarify the behavior of the viscosity coefficients.

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Plasma Jet Temperature Study. Appendix I—**Spectral Line Constants.** Appendix II—**Plasma Sources.** Appendix III—**Radial Distributions.** Appendix IV—**Spectrographic Equipment.** W. J. Pearce. *USAF WADC TR 59-346*, Feb., 1960. 104 pp. 47 refs. Comparison of spectral methods for measuring plasma temperatures in the range of 5,000° to 15,000°K. For plasma jets, the best method is to determine the temperature from the intensities of atomic lines or of ionic lines. Tables of values of the required constants are computed and examples of various modifications of the method are given.

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Maintained Detonations. B. V. Voitsekhovskii. (*AN SSSR Dokl.*, Dec. 21, 1959, pp. 1254–1256.) *Sov. Phys. - Dokl.*, May-June, 1960, pp. 1207–1209. Translation. Presentation of the millimicrosecond detonation processes in a channel when the supply of the original gas mixture is continuously filling the space in front of a detonation wave at a sufficiently high rate, thus creating a continuous and steady state. The experimental arrangement is described.

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The Investigation of Exact Solutions of Nonstationary Diffraction Problems in the Neighborhood of Wave Fronts. V. S. Buldyrev. (*AN SSSR Dokl.*, Nov. 11, 1959, pp. 291–294.) *Sov. Phys. - Dokl.*, May-June, 1960, pp. 1218–1221. Translation. Analysis of the convergence of the wave-field expansion in powers of the parameter γ, the parameter depending on the distance between the point investigated and the front wave. It is shown that, in the case of isotropic acoustic media separated by a boundary in the form of a circular cylinder or a sphere, one can form a series in powers of γ which converges near the front and which, in certain cases, represents the field exactly and, in other cases, with an accuracy up to the term which is an analytic function of the coordinates and of time.

Electron Diffusion Ahead of Shock Waves in Argon. H. D. Weymann. (*U. Md. Inst. Fluid Dynamics & Appl. Math. TN BN-197*, Mar., 1960.) *Phys. Fluids*, July-Aug., 1960, pp. 545–548. AFOSR-supported investigation performed with electrostatic and magnetic probes to determine the electron diffusion ahead of shock waves of $M_s = 8$ to 12 in argon.

The Simplest Problems Concerning Gas-Ionizing Shock Waves in an Electromagnetic Field. A. G. Kulikovskii and G. A. Lyubimov. (*AN SSSR Dokl.*, Nov. 21, 1959, pp. 525–528.) *Sov. Phys. - Dokl.*, May-June, 1960, pp. 1195–1198. Translation.

Energy Transfer in a Turbulent Fluid. B. S. Tanenbaum and David Mintzer. *Phys. Fluids*, July-Aug., 1960, pp. 529–538. ONR-supported presentation of a method of using experimental measurements of two- and three-velocity correlation functions to provide a direct test of energy transfer hypotheses in a turbulent fluid. By using this method, the optimal values for the three empirical parameters m, n, and γ, which appear in the general transfer function proposed by von Kármán, are determined from the correlation function data of Stewart and Townsend.

Internal Flow

Simplified Analysis of a Thrust-Augmentation System. K. L. Bergman. *ASME Trans., Ser. E - AM*, June, 1960, pp. 358, 359. Investigation showing that with a diffuser on the exit, larger values of thrust augmentation are possible, and that these values are very sensitive to the secondary nozzle and diffuser efficiencies. Incompressible, one-dimensional flow is assumed.

Controlled Radial Energy Gradient in Axial Flow Compressors. E. M. Rex. *Aerospace Engrg.*, Oct., 1960, pp. 22, 23, 64, 67. Presentation of a method for applying two-dimensional analysis to high-performance engines. This involves keeping the axial velocity constant, obtaining equal work at all radii, and accounting for simple radial equilibrium without having free vortex flow and its resulting mass flow limitations. If a special first stage is used, the entering enthalpy gradient to later stages is at the designer's discretion.

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Design and Test of Mixed-Flow and Centrifugal Impellers. J. J. Kramer, W. M. Osborn, and J. T. Hamrick. (*ASME Hydraulic Conf., Ann Arbor, Apr. 13–15, 1959, Paper 59–Hyd-20.*) *ASME Trans., Ser. A - EP*, Apr., 1960, pp. 127–134; Discussion, R. C. Dean, Jr., p. 135. 13 refs. Presentation of procedures for designing the hubshroud contour and the blade shape of mixed-flow and centrifugal impellers, and evaluation in terms of experimental results obtained for impellers designed by these methods. Additional experimental results with varying boundary-layer allowance and some vaned diffuser test results are also presented.

The Flow Field in the Diffuser of a Radial Compressor. I. L. Ryhming. *J. Aerospace Sci.*, Oct., 1960, pp. 798, 799.

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Remarks on the Eddy Viscosity in Compressible Mixing Flows. Lu Ting and P. A. Libby. *J. Aerospace Sci.*, Oct., 1960, pp. 797, 798. Application of Mager's method to find a relation between the compressible and incompressible eddy viscosities for two-dimensional mixing flows.

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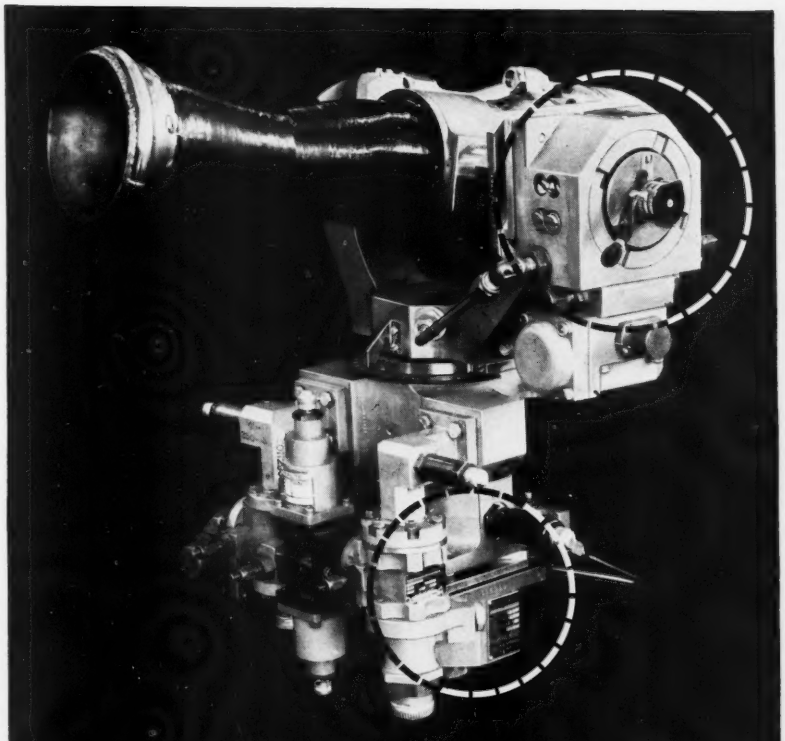

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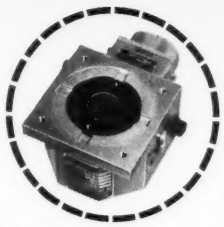

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IMPORTANT

PROGRESS TOWARD ADVANCED

AIRCRAFT

—THROUGH NUCLEAR POWER

—the flight vehicle which can live in the air as easily and confidently as a ship lives in the sea— will be powered by a nuclear reactor, the only source of energy which can provide virtually unlimited range and endurance for aircraft, for high altitude or on the deck, long range military air missions.

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But today, little more than nine years later, the Aircraft Nuclear Propulsion Department of General Electric has developed and demonstrated the basic technology required to build and fly a high performance aircraft nuclear propulsion system.

During the 9-year span of effort, General Electric engineers and scientists have achieved major breakthroughs in reactor technology, shielding techniques, high temperature resistant materials, specialized controls capable of functioning reliably in a high density radiation environment, and in other areas.

One of these technical achievements is discussed to the right in capsule article form. In succeeding announcements other interesting technical advances at the Aircraft Nuclear Propulsion Dept. of General Electric will be discussed.

ADVANCES IN NUCLEAR SHIELDING TECHNIQUES

As the shield is the largest weight item in the propulsion system, major effort has been applied to shield theory, experiment and design since the initiation of the Aircraft Nuclear Propulsion program.

The dimensions of the problem faced are evident when you consider that General Electric engineers had to find a way to reduce shielding weights from hundreds and thousands of tons for stationary nuclear power plants by orders of magnitude.

One of the major gains registered was the concept of the divided shield, i.e. dividing the shielding between the power plant and the crew compartment. This concept takes advantage of the fact that even the most sensitive component of the system can withstand 10,000 times the amount of nuclear radiation that a human being can tolerate.

This concept has been defined through the use of improved analytical techniques to produce detailed radiation patterns around reactor shield assemblies. New computer programs, and new calculation techniques developed at General Electric have yielded invaluable data for the design of sophisticated shielding configurations.

Additional improvements have been attained through study of materials. Materials not formerly employed for reactor use have been developed and applied. Design techniques have been created which take maximum advantage of these materials.

These theoretical and experimental investigations have resulted in shields which are so light that nuclear aircraft need be no heavier than present day airplanes. Shielding weight is no longer a critical problem.

Although much has been accomplished, further improvements in shielding technology are being developed through improved calculation methods, advanced materials development and more sophisticated structural design.

Opportunities exist today for Engineers and Scientists from many disciplines to contribute to precise solutions of a variety of sophisticated problems pertaining to the final development stage of General Electric's nuclear propulsion system for high performance aircraft.

Openings available in both Cincinnati, Ohio and Idaho Falls, Idaho for:

Metallurgists; Ceramists; Mathematicians; Technical Editors; Mechanical, Electrical, and Chemical Engineers; Nuclear and Solid State Physicists; Physical Chemists.

If you have an interest, and qualifications, in any of these areas, please write in confidence to: Mr. George Hunsinger, *Manager, Professional Personnel. Room* 2-MK.

AIRCRAFT NUCLEAR PROPULSION DEPARTMENT

GENERAL ELECTRIC

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for the three purposes of countermeasures: detection, deception, and denial.

Amplifiers

An Introduction to the Theory of Solid-State Masers. P. N. Butcher. *(IEE Paper 3220 E.) IEE Proc., Pt. B,* July, 1960, pp. 341–351. 14 refs. Discussion of the solid-state maser theory, with particular reference to the traveling-wave maser. The relevant properties of paramagnetic ions are described, and the quantum theory of maser action is outlined quantitatively. A semi-classical treatment is developed and used to evaluate the engineering characteristics of a traveling-wave maser which employs the comb type of slow-wave guide.

Antennas, Radomes

Half-Wave Cylindrical Antenna in a Dissipative Medium: Current and Impedance. Ronold King and Ch. W. Harrison. *J. Res., Sect. D - RP,* July–Aug., 1960, pp. 365–380. 23 refs.

O Edinstvennosti Resheniia Integral'nykh Uravnenii Teorii Antenn (Pervogo Roda). N. N. Govorun. *AN SSSR Dokl.,* May 1, 1960, pp. 91–94. In Russian. Determination of the uniqueness of solution for previously derived first-order integral equations to cover the case of an ideally conducting antenna.

Van Atta Reflector Array. E. D. Sharp and M. A. Diab. *IRE Trans., AP Ser.,* July, 1960, pp. 436–438. Evaluation of the Van Atta reflector array in which the elements are interconnected to reradiate received energy back in the direction of arrival. Scattering cross section measurements on a four-by-four Van Atta array of 16 dipoles are presented.

A Wide-Band Transverse-Slot Flush-Mounted Array. E. M. T. Jones and J. K. Shimizu. *IRE Trans., AP Ser.,* July, 1960, pp. 401–407. Discussion of the design analysis and measured performance of an antenna composed of an *H*-plane array of parallel wave guides having quarter-wavelength-thick transverse slots extending completely across the array. The discussion is illustrated by the design and evaluation of an experimental antenna with a radiating aperture 9 in. wide and 20 in. long.

Unequally-Spaced, Broad-Band Antenna Arrays. D. D. King, R. F. Packard, and R. K. Thomas. *IRE Trans., AP Ser.,* July, 1960, pp. 380–384. USAF-sponsored presentation of the requirements for a broad-band, steerable linear antenna array. The limitations due to grating lobes of an equally-spaced array are discussed. Results are given of the study of several different unequally-spaced arrays. A scheme for controlling the cosine arguments in the radiation pattern formula is given which has resulted in one of the best patterns of this study of unequally-spaced arrays.

Paraboloidal Reflector Patterns for Off-Axis Feed. S. S. Sandler. *IRE Trans., AP Ser.,* July, 1960, pp. 368–379. 12 refs. USAF-Army-supported discussion of the problem of predicting the radiation pattern for an asymmetrically illuminated paraboloid. The current distribution method is given in a final form suitable for machine computation. An approximate analytical solution using scalar diffraction methods is compared with the experimental results and the machine solution.

Mutual Coupling Effects in Large Antenna Arrays. II—Compensation Effects. S. Edelberg and A. A. Oliner. *IRE Trans., AP Ser.,* July, 1960, pp. 360–367. USAF-supported discussion of the reduction of the variation in the input impedance by the use of a compensating structure which appropriately modifies the environment of the array. A two-dimensional dipole array is treated as a typical example, and its input impedance is calculated by means of a unit cell equivalent network as a function of scan angle for different environmental situations.

Circuits & Components

Magnetic Phase Correction Circuits. R. C. Barker and A. J. Gruodis. *USAF WADC TR 59-237 [AD 214885],* Mar., 1960. 130 pp. 15 refs. Discussion of circuits which differentiate and integrate the modulation on a supressed-carrier signal by, respectively, taking finite differences and by accumulation. Also, techniques are presented for altering magnetic amplifier design to produce integration and differentiation.

Communications

Radio Command Set for High-Altitude Balloons. R. W. Frykman. *Electronics,* Aug. 26, 1960, pp. 54, 55. Presentation of the requirements and design of lightweight, reliable radio command equipment, including both balloon-borne and ground-based component systems.

Dielectrics

Determination of the Dielectric Properties of Low-Loss Ceramics at Q-Band Frequencies. J. M. Free and G. B. Walker. *(IEE Paper 3223 M.) IEE Proc., Pt. B,* July, 1960, pp. 354–356.

The Influence of Polarization Effect on Energy Loss of Electrons Passing Through Dielectrics. Hsiao Chen-hsi and Chou Teh-lin. *Acta Physica Sinica,* Feb., 1960, pp. 98–106. 17 refs. In Chinese, with summary in English. Investigation using the Wilson cloud chamber filled with hydrogen to measure the average and most probable energy losses of 0.3–1.0 Mev electrons passing through beryllium, carbon, and aluminum foil.

Magnetic Devices

Magnetic Anomaly Simulator for Use with Magnetic Airborne Detectors (M.A.D.). E. A. Godby and R. C. Baker. *Canada, NRC DME/NAE Quart. Bul. No. 2,* Apr. 1–June 30, 1960, pp. 1–18.

Vliianie Neravnomernosti Namagnichivaniia na Staticheskie Kharakteristiki Serdechnika. I. G. D. Kozlov. *Avtom. i Telemekh.,* Jan., 1960, pp. 119–134. In Russian. Presentation of a method for determining the effect of magnetization nonuniformity on the static characteristics of the core for various geometries and rates of magnetic polarity reversal.

Obobshchennye Usloviia Sorazmernosti Elektromagnitnykh Sistem (Geometriia Elektromagnitnykh Sistem). A. S. Tulin. *Avtom. i Telemekh.,* Mar., 1960, pp. 374–383. In Russian. Discussion covering the problem of the geometry of electromagnetic systems. Various optimum configurations are indicated, which furnish the choice for specific application on the basis of technical and economic requirements.

Sil'nye Magnitnye Polia. G. M. Strakhovskii and N. V. Kravtsov. *Uspekhi Fiz. Nauk,* Apr., 1960, pp. 693–714. 124 refs. In Russian. Survey of the research done on strong magnetic fields and their application, and discussion covering electromagnets with iron cores, nonferrous constant electromagnets, pulse magnetic fields, the shape and duration of the field impulse, and means for measuring pulse magnetic fields.

Spisok Literatury po Magnitnym Elementam Avtomatiki, Telemekhaniki i Vychislitel'noi Tekhniki za 1958 g. I, II. G. V. Subbotina and I. S. Trefilova. *Avtom. i Telemekh.,* Jan.; Feb., 1960, pp. 271–278; 149–158. 328 refs. In Russian. Comprehensive survey of the literature on magnetic elements for 1958, covering ferromagnetic materials; nonlinear magnetics; magnetic amplifiers, their theory and applications; magnetic amplifiers, modulators, magnetometers; discrete magnetic elements; magnetic generators and frequency transformers; and measurements and methods for testing magnetic elements.

Networks, Filters

The Nature and Behavior of Redundancy Networks and Functions. Fred Moskowitz. *USAF RADC TR 60-4,* May, 1960. 186 pp. 33 refs. Investigation of various properties and characteristics of probabilistic redundancy networks and functions which can be used to represent reliability relationships in complex equipment containing redundant elements, and in large-scale systems containing a multiplicity of alternative subsystems or telecommunication nets containing possibilities of alternative routing.

Comparative Investigations of Image and Insertion Parameter Filters. Heinrich Simon. *KTH Trans. 156,* 1960. 58 pp. 27 refs. Comparative study of image and insertion parameter filters of the same structure. The comparison is made principally in terms of matching characteristics. The image impedance and image cut-off frequency of insertion parameter filters are calculated, and the matching mechanism is explained in terms of image parameter theory.

Power Supplies

Fuel Cells: Introduction. L. D. McGraw. *SAE Summer Meeting, Chicago, June 5–10, 1960, Preprint 179A.* 10 pp. Discussion of fuel cells as specialized batteries, including the technical and economic aspects of battery power sources.

A Nitrosyl Chloride Solar Regenerative Fuel Cell System. W. E. McKee, J. D. Margerum, E. Findl, and W. B. Lee. *SAE Summer Meeting, Chicago, June 5–10, 1960, Preprint 179C.* 10 pp. Discussion of some of the problems and theoretical aspects of a photochemical type of solar regenerative system, including a status report on the regenerative nitrosyl chloride fuel cell system now being developed.

Transistor Inverters and Converters. I—Basic Principles of the Ringing-Choke System. M. D. Berlock and H. Jefferson. *Wireless World,* Aug., 1960, pp. 399–402. Discussion of the design and of the mode of operation of a "blocking-oscillator inverter (or converter)."

Assessment of the Feed-Back Vectors Required to Stabilise a Carbon Pile Regulator Controlled Aircraft D.C. Generator with Regenerative Loads. D. O. Burns. *Gt. Brit., RAE TN El. 177,* Apr., 1960. 26 pp.

Principles of Thermoelectric Devices. H. J. Goldsmid. *Brit. J. Appl. Phys.,* June, 1960, pp. 209–217. 26 refs. Discussion of the Seebeck effect and of the possible improvements in semiconductors—i.e., by alloying with isomorphous materials. Construction and performance of thermoelectric refrigerators and small scale thermoelectric devices are considered.

Preobrazovanie Teplovoi Energii v Elektricheskuiu s Pomoshch'iu Termoelektronnoi Emissii. N. D. Morgulis. *Uspekhi Fiz. Nauk,* Apr., 1960, pp. 679–692. 28 refs. In Russian. Historical survey of the development in the field of conversion of thermal energy into electric energy by means of thermoelectronic emission.

Air Force Space Vehicle Power Program. I—USAF Expands Energy Conversion Effort. II—Megawatt Power Levels Sought for Space. P. J. Klass. *Av. Week & Space Tech.,* Aug. 15; 22, 1960, pp. 83, 85–90 (ff.); 69, 71, 72–81 (ff.). Survey of current WADD programs in photovoltaic cell technology, thermoelectric and thermionic conversion, both regenerative as well as unregenerative fuel cells, solar dynamic systems, and programs in the area of rotating machines for space use. Included is also a discussion of the program to develop the 300 kw. Spur (Space Power Unit) Reactor.

Radar

The Theory and Design of Chirp Radars. J. R. Klauder, A. C. Price, S. Darlington, and W. J. Albersheim. *Bell System Tech. J.,* July, 1960, pp. 745–808. 20 refs. Development of a radar technique that provides a solution for the conflicting requirements of simultaneous long-range and high-resolution performance. This technique, called Chirp, recognizes that resolution depends on the transmitted pulse bandwidth. A long high-duty-factor transmitted pulse with suitable modulation (linear frequency modulation), which covers a frequency interval many times the inherent bandwidth of the envelope, is employed.

Radar Echoes from Birds. M. G. H. Ligda. *(OSTIV 7th Congr., Leszno, Poland, June, 1958.) Schweizer Aero-Rev.,* Mar., 1960, pp. 187, 188.

The Design of Radar Signals Having Both High Range Resolution and High Velocity Resolution. J. R. Klauder. *Bell System Tech. J.,* July, 1960, pp. 809–820. Discussion of some fundamental limitations on simultaneous range-velocity determination in terms of ambiguity diagrams, with the aid of a quantum mechanical analog to the Wigner distribution function.

An Analysis of Radar Profiles Over Mountainous Terrain. H. K. Lyytikainen. *Photogrammetric Eng.,* June, 1960, pp. 403–412. Investigation of Arizona APR (airborne profile recorder) flights which shows that the use of radar elevations is possible in very rugged country. Discussed are the experimental material; establishment of reference data; calibration of the radar beam, divergence angle, and beam width; and test result analysis.

Broad-Band Frequency Scanning Radar System. S. R. Hennies and J. V. N. Granger. *Electronics,* Sept. 2, 1960, pp. 44–47. Discussion of the performance capabilities, principles of operation, and design of a radar system which covers a wide range of frequencies at a high rate of frequency scan, and which has a novel arrangement for detecting Doppler shifts caused by target motion.

FM-CW Radar Now More Attractive to Guidance Designers. G. J. Bonnelle. *Space/Aeronautics,* Aug., 1960, pp. 143–148. Review of difficulties encountered in early C-W radar designs and of their new development. A modern FM/C-W radar is described and the FM/C-W system is compared with pulse Doppler and non-coherent pulse radars.

Semiconductors

Techniques for Application of Transistors in Military Equipment. R. S. Whitlock and William von Alvin. *USAF WADC TR 59-707,* Jan., 1960. 165 pp. Discussion relating the information commonly set forth in transistor specifications to the problems of equipment design. Transistor ratings, characteristics, and variability of properties are discussed along with certain statistical techniques for relating the variability information to analytical expressions useful in circuit design. Numerical data and special design considerations for specific transistor types are presented.

Single Domain Criteria and Their Implications. Henri Amar. *USAF WADC TR 59-547,* Oct., 1959. 19 pp. 25 refs.

Anizotropiia Gal'vanomagnitnogo Effekta v Kristalle Germaniia *n*-Tipa pri Temperaturakh Perekhodnoi Oblasti Provodimosti. R. G. Annaev and A. Allanazarov. *AN SSSR Dokl.,* May 21, 1960, pp. 557–560. 10 refs. In Russian. Study of the anisotropy of the galvanomagnetic effect in a germanium crystal of the *n*-type under the effect of temperatures in the transient region of conductivity.

Telemetry

Radar Data Transfer System AN/TRQ-10 (XW-1)/GR. G. K. Bennison and M. M. McCormick. *USAF RADC TR 60-38,* Apr., 1960. 104 pp. Presentation of the design, theory of operation, and evaluation of a radar data transfer system. The system operates in

INTERNATIONAL AERONAUTICAL ABSTRACTS

A Review of Worldwide Scientific and Technical Literature

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ACOUSTICS, SOUND, NOISE

ON THE GENERATION OF SOUND BY SUPERSONIC TURBULENT SHEAR LAYERS. O. M. Phillips. J. Fluid Mech., Sept., 1960, pp. 1-28. 15 refs. Development of a theory to describe the generation of sound by turbulence at high Mach numbers. The problem is formulated in terms of the fluctuating pressure, and a convected wave equation is derived to describe the generation and propagation of the pressure fluctuations. The supersonic turbulent shear zone is examined in detail. It is found that, at supersonic speeds, sound is radiated as eddy Mach waves, and as the Mach number increases, this mechanism of generation becomes increasingly dominant. Attention is concentrated on the properties of the pressure fluctuations just outside the shear zone where the interactions among the weak shock waves have had little effect. An asymptotic solution for large Mach number is derived by a Green's function technique, and it is found that radiation with given frequency n and wave number k can be associated with a corresponding critical layer within the shear zone.

TRANSONIC PERFORMANCE CHARACTERISTICS OF SEVERAL JET NOISE SUPPRESSORS. J. W. Schmeer, L. B. Salters, Jr., and M. D. Cassetti. US, NASA TN D-388, July, 1960. 48 pp. OTS, $1.25. Discussion of the results of an investigation on the transonic aerodynamic performance characteristics of six noise-suppressor nozzles using a hot jet exhaust provided by a hydrogen peroxide system. The 12-tube and 12-lobe nozzles had the lowest internal losses at static conditions and the 8-lobe nozzle with centerbody, shroud, and secondary air had the least propulsive losses at transonic speeds.

CORRELATION OF NOISE PRESSURES AND OF THE INDUCED STRAINS IN AN AIRCRAFT STRUCTURE. I - CORRELATION OF PRESSURES AROUND A JET ENGINE. II - NOTE ON THE USE OF CORRELATION TECHNIQUES TO DETERMINE THE FORMS OF VIBRATION OF A CONTINUOUS STRUCTURE EXCITED BY RANDOM PRESSURES. B. L. Clarkson. (WADC Minn. Conf. on Acoustic Fatigue, Oct., 1959.) U. Southampton Dept. Aeron. & Astron. Rep. 108, Dec., 1959. 27 pp. Presentation of an outline for the characteristics of the noise pressure correlation in the region surrounding a jet exhaust. In the near field of the jet, which is usually the region of most interest from the structural point of view, it is necessary to rely on experimentally determined values of correlation. A preliminary investigation into the multimodal type of vibration taking place in a tailplane structure excited by jet noise is then described. Strain correlation measurements indicate the mode of vibration at each resonant frequency.

AERODYNAMICS, FLUID MECHANICS

Aerothermochemistry, Dissociation, Ablation

SUR L'AEROTHERMODYNAMIQUE DES PAROIS FONGIBLES. Th. Moulin and J. J. Bernard. 2nd ICAS Congr., Zurich, Sept. 12-16, 1960, Preprint. 17 pp. 13 refs. In French. Study covering the aerothermodynamics of ablation surfaces. It is shown, depending upon bleeding or injection in the boundary layer, that the asymptotic behavior of the solution of the simplified system of laminar boundary-layer equations is algebraic or exponential at large values of Prandtl or Schmidt numbers. These solutions still apply for relatively moderate values of these parameters and can be adapted to known solutions which are mentioned briefly along with the corresponding limiting hypotheses. Also indicated are some approaches which lead to sufficiently accurate and general solutions not involving major mechanical computations. Within the material itself, the thermal phenomena involve the characteristics of thermal conductivity and ablation of the material. The solutions of the heat equation, obtained by several methods of calculation, are discussed. Finally, some experimental observations made in wind tunnels at moderate temperatures on simulation materials (plexiglas) are compared with theoretical predictions.

PARTICLE IMPACTS ON THE MELT LAYER OF AN ABLATING BODY. E. W. Ungar. (ARS Struc. Des. of Space Vehicles Conf., Santa Barbara, Apr. 6-8, 1960.) ARS J., Sept., 1960, pp. 799-805. Army-supported analysis considering the effects of high velocity particle impacts on a melting body consisting of a composite of glass and plastic which evolves a large quantity of gas. An equation is developed relating the increase in erosion rate, as a result of particle impacts, to flight and material parameters. It was assumed in the derivation that the liquid melt layer protects the underlying solid body by decelerating the particles. The extent of the melt layer protection was found to be dependent on the particle size and melt layer thickness. The computed melt layer thickness agreed with that observed on glass-reinforced Micarta 259-2 test specimens which were exposed in a rocket exhaust jet.

ANALYSIS OF THE ABLATION OF PLASTIC HEAT SHIELDS THAT FORM A CHARRED SURFACE LAYER. R. J. Barriault and J. Yos. ARS J., Sept., 1960, pp. 823-829. 10 refs. Analysis considering a model composed of a porous outer layer through which there is a counterflow of gases from the thermal decomposition of the plastic. The charred layer is backed by a semi-infinite layer of the undecomposed solid. The transpiring gases are considered to be in thermal equilibrium with the skeleton of the porous material. The heat-transfer equations are developed and the steady-state solution is obtained. The formulas for the steady-state temperature distributions, charred layer thickness, and heat of ablation are derived in terms of model parameters and variables of the thermal environment. An approximate formula is also derived for the induction time of the nonsteady phase of ablation.

Aerothermodynamics

AN INTEGRAL METHOD FOR NATURAL-CONVECTION FLOWS AT HIGH AND LOW PRANDTL NUMBERS. W. H. Braun and J. E. Heighway. US, NASA TN D-292, June, 1960. 40 pp. 13 refs. OTS, $1.00. Analysis of the boundary layer at two regions, the thermal and the viscous. Separate polynomials are used to approximate the temperature and velocity profiles in the two regions and are then matched at the interface. Comparisons with numerical solutions of the flow over a flat plate show improvements over other integral methods. Application is made to flow over a cone.

VARIATION IN HEAT TRANSFER DURING TRANSIENT HEATING OF A HEMISPHERE AT A MACH NUMBER OF 2. R. D. English and H. S. Carter. US, NASA TN D-399, June, 1960. 26 pp. OTS, $0.75. Presentation of results of heat-transfer tests on a 5-in.-diam. hemisphere to determine the variation of Stanton number with the ratio of wall temperature to total temperature. The tests were made at stagnation temperatures of 760°R., 1,030°R., and 1,380°R. The model was constructed so that radiation effects and also streamwise conduction effects within the model skin were minimized, and the tests verified that these effects were small. For laminar flow on the hemisphere, the Stanton number remained essentially constant as the ratio of wall temperature to total temperature increased. However, for fully established turbulent flow, the Stanton number at some stations decreased on the order of 50% as the ratio of wall temperature to total temperature increased. A theory which agreed fairly well with the trend of this decrease is shown for comparison.

EXPERIMENTAL INVESTIGATION OF THE DOWNSTREAM INFLUENCE OF STAGNATION POINT MASS TRANSFER. P. A. Libby and R. J. Cresci. USAF WADC TN 59-210, Apr., 1960. 44 pp. 20 refs. Presentation of the results of an investigation into the downstream influence of localized mass transfer in the stagnation region of a blunt body under hypersonic flow conditions. The coolant is injected through a porous plug coaxial with the centerline of symmetry of the model. The tests were carried out in a Mach 6 wind tunnel with stagnation temperatures of approximately 1,600°R. and with a stagnation pressure of approximately 600 psia. Four different gases were injected over a range of mass flows. The heat transfer on the impermeable section was measured under isothermal wall conditions; for the higher rates of mass flow, adiabatic surface temperatures were also determined. Similarity parameters for the flow system are established on the basis of an analysis of the boundary-layer flow. These parameters permit the extrapolation of the test results to other flow conditions, provided laminar flow prevails. Helium is found to be the most effective coolant.

A STANDARD FORMULATION OF THE STEADY CONVECTIVE MASS TRANSFER PROBLEM. D. B. Spalding. Internatl. J. Heat & Mass Transfer, Aug., 1960, pp. 192-207. 41 refs. Development of a convective mass transfer theory to calculate the rate of transfer of material across a stream boundary. It is shown that, provided certain relations exist between the transport properties, every mass transfer problem, including those with simultaneous heat transfer and chemical reaction, can be expressed by relations of an "Ohm's law" type: $\dot{m}'' = gB$, where $\dot{m}''$ is the required mass transfer rate through the surface, g is a surface conductance dependent on aerodynamic factors, and B is a dimensionless driving force dependent on the thermodynamic properties of the main stream, the fluid in contact with the phase boundary, and the transferred substance. The standard formulation is derived from the differential equations of conservation and flux and by reference to a wall-flux boundary condition.

THE INFLUENCE OF LOW WALL TEMPERATURE ON BOUNDARY-LAYER TRANSITION AND LOCAL HEAT TRANSFER ON 2-INCH-DIAMETER HEMISPHERES AT A MACH NUMBER OF 4.95 AND A REYNOLDS NUMBER PER FOOT OF 73.2×10^6. Morton Cooper, E. E. Mayo, and J. D. Julius. US, NASA TN D-391, July, 1960. 37 pp. 14 refs. OTS, $1.00. Presentation of the results of measurements on the location of boundary-layer

transition and the local heat transfer. The initial values of the wall-to-stream stagnation-temperature ratios were 0.16 (cold tests) and 0.65 (hot tests). During two of the four cold tests, the boundary-layer flow changed from turbulent to laminar over large regions of the hemisphere as the model heated. On the basis of a detailed consideration of the magnitude of roughness possibly present during these two cold tests, it appears that this destabilizing effect of low wall temperatures (cooling) is not caused by roughness as a dominant influence.

EXPERIMENTAL DETERMINATION OF THE TURBULENT HEAT TRANSFER RATE DISTRIBUTION ALONG A BLUNT FACED BODY FROM SHOCK TUBE EXPERIMENTS. E. Offenhartz and H. Weisblatt. Avco Res. & Adv. Devel. Div. RAD TR 2-58-16, July 7, 1960. 23 pp. 10 refs. Reprint. USAF-supported investigation showing that for a 0° angle of attack along the forebody of the model, the momentum theory is the upper bound to the data at the midpoint of the forebody. The data then decreased to the incompressible turbulent flat plate value at the end of the forebody (in the vicinity of the sonic point). Along the conical afterbody, both laminar and turbulent heat transfer rates were correlated by simple incompressible flat plate theory. At angle of attack, the heat transfer measurements were correlated in terms of the measured heat transfer rates at angle of attack to zero values. A simple engineering approach allowed the calculation of this ratio for both the laminar and turbulent flow regimes.

HEAT TRANSFER RATE DISTRIBUTION FOR A CONICAL AFTERBODY AT 0, 5, AND 10 DEGREES ANGLE OF ATTACK. E. Offenhartz and H. Weisblatt. Avco Res. & Adv. Devel. Div. RAD TM 2-58-105 (Aerody. Sect. Memo. 182), July 6, 1960. 25 pp. Reprint. USAF-supported investigation showing that at 0° angle of attack, the incompressible flat plate theory adequately described the data trend. Heat transfer rate data obtained at angle of attack was compared to 0° data, and it was found that maximum changes in the heat transfer rate distribution occurred along the windward-leeward plane. At 5° angle of attack, the maximum increase in the heat transfer rate was 30% and occurred along the windward portion of the conical afterbody. For 10° angle of attack, the heat transfer rate on the windward portion of the afterbody was found to be 2.7 times the 0° rate.

Boundary Layer

THE FLOW PAST A FLAT PLATE OF FINITE WIDTH. J. W. Elder. J. Fluid Mech., Sept., 1960, pp. 133-153. 23 refs. Investigation of certain three-dimensional boundary layers in an incompressible fluid for the Reynolds number range of 10^4 to 10^6, with particular emphasis on the flow near the side edge. The laminar velocity field is everywhere convex and does not contain any secondary flow other than that of the edge where the stress is controlled by the local radius of curvature. The excess skin friction due to the edge is considerably greater than that given by calculations based on the Rayleigh approximation, but agrees with a recent Pohlhausen calculation by Varley. Near the edge, the high stress and ease of momentum diffusion makes the flow very unstable, and turbulent spots occur well upstream of the normal transition zone in the middle of the plate. In fully turbulent flow, when the secondary flow is largely localized to within a few boundary-layer thicknesses of the edge, the secondary flow velocities are everywhere less than 0.04 of the free-stream velocity. Nevertheless, the secondary flows from each side interact to increase the total drag coefficient.

EFFECTS OF FIXING BOUNDARY-LAYER TRANSITION FOR A SWEPT- AND A TRIANGULAR-WING AND BODY COMBINATION AT MACH NUMBERS FROM 0.60 TO 1.40. L. S. Stivers, Jr. US, NASA TN D-312, June, 1960. 28 pp. 14 refs. OTS, $0.75. Investigation using two small-scale wing-body models to determine the aerodynamic effects of fixing boundary-layer transition for swept- and a triangular-wing configurations. The wings had an aspect ratio of 2.99 and 3%-thick biconvex sections. Lift, pitching-moment, and drag data were obtained at Mach numbers from 0.60 to 1.40 for angles of attack from -2° to about 15°. The Reynolds number for the test was generally 1.5 million. Minimum drag data were obtained for both configurations over a range of Reynolds numbers from 1.0 million to about 3.0 or 4.0 million.

SOME EFFECTS OF SURFACE CURVATURE ON THE LAMINAR BOUNDARY LAYER FLOW. K. Toba. Rensselaer Polytech. Inst. Dept. Aero. Eng. TR AE 5904 (AFOSR TN 60-448), Mar., 1960. 24 pp. Extension of Yen's theory of laminar boundary layer flow that adopts the natural coordinates of the boundary layer approximation to take into account the surface curvature effects. Further elaboration of the proposed formulation is made and the effects of surface curvature are evaluated for a family of surfaces which yield similar solutions. Numerical results for the velocity profiles and the wall skin friction distribution obtained by means of a high-speed computer are presented and analyzed.

Flow of Fluids

DETERMINATION OF THE TIME HISTORY OF THE FLOW FIELD ABOUT VARIOUS BLUNT BODY SHAPES AND SIZES DURING EXPERIMENTS IN 1.5-INCHES DIAMETER SHOCK TUBE. E. Offenhartz and H. Weisblatt. Avco Res. & Adv. Devel. Div. RAD TR 2-58-10, July 25, 1960. 74 pp. Reprint. USAF-supported investigation of the time history of flow about blunt bodies that was found to consist of three distinct intervals. The first time interval, or bow wave build-up time, occurred immediately after the normal shock has passed the model. During this interval the bow wave formed, moved forward from the body, and assumed a steady state shape and position. The second time interval, or steady state, lasted until the onset of the third or unsteady flow phase. This last interval started when the bow wave interaction with the

turbulent boundary layer on the shock tube walls caused changes to the bow wave. During this interval, the bow wave first distorted at the walls, then changed shape and became more normal with time. Heat transfer measurements using calorimeter gages were found to be sensitive to the entire time history of the flow field. Results are presented which enable determination of the steady state portions of heat transfer measurements.

PROBLEM OF NEARLY SELF-SIMILAR UNSTEADY MOTION. T. G. Koldobskaya. (Leningrad U. Vestnik, No. 1, 1960, pp. 111-122.) ARS J. Suppl., Sept., 1960, pp. 853-859. Translation. Analysis of unsteady, nearly self-similar motion by perturbing basic self-similar flow and linearizing the resulting equations. A transformation is used to make the new flow self-similar by reducing the number of independent variables. The technique is discussed for nearly wedge-shaped and nearly conical bodies.

SOME REMARKS ON THE MAGNETOGASDYNAMIC LINEARIZED THEORY. Shigenori Ando. Phys. Soc. Japan J., Aug., 1960, pp. 1523-1533. Extension of the general theory of magnetogasdynamic linearized flow to cover the case of unsteady flow in an arbitrary direction with respect to the magnetic field. This theory is also valid in the case when the reference frame is considered as the "body axis" slightly inclined against the free stream direction. For the case of steady flow, a quadratic expression for the pressure distribution is derived. As illustrations, some problems of weak electromagnetic interaction are solved, namely, for a two-dimensional thin wing and an axisymmetric body.

SUB- AND SUPER-ALFVENIC FLOWS PAST BODIES. W. R. Sears and E. L. Resler, Jr. 2nd ICAS Congr., Zurich, Sept. 12-16, 1960, Preprint. 15 pp. 25 refs. USAF-Navy-supported discussion of contrasts between super- and sub-Alfvénic flows in terms of the following categories of sub-Alfvénic phenomena: (1) upstream wakes, (2) upstream-inclined waves, and (3) elliptic supersonic and hyperbolic subsonic flows; negative lift of airfoils at positive incidence. These phenomena are discussed with a view toward explaining their origins. It is concluded that none violates simple physical principles, but that the lift produced in elliptic sub-Alfvén regimes cannot be predicted with confidence until the analog of the Kutta-Joukowski condition is understood. Finally, an attempt is made to assess the probability of laboratory observations of these phenomena. It is concluded that values of the magnetic Reynolds number can be realized that will permit these effects to be studied before they are attenuated by diffusion.

FLOW BEHIND SHOCK WAVES IN CONDUCTING GASES. R. P. Kanwal. Royal Soc. (London) Proc., Ser. A, Sept. 6, 1960, pp. 263-268. 11 refs. Study of the vorticity and current density behind a shock wave, considering mainly plane steady flows. It is shown that in addition to generating vorticity, the shock waves also generate electricity. Secondly, the expression for vorticity in conducting gases, in contrast to nonconducting gases, depends on the thermodynamic behavior of the fluid. Finally, a relation is developed between the normal components of the vorticity and current density vectors behind the shock wave.

EXPERIMENTAL INVESTIGATIONS OF THE INTERACTION BETWEEN A SHOCK AND A MAGNETIC FIELD. J. P. Barach. U. Md. Inst. Fluid Dynamics & Appl. Math. TN BN-203 (AFOSR TN 60-439), Mar., 1960. 29 pp. 12 refs. Study of the magnetic interaction observed with flows of Mach number about 15 in krypton and inhomogeneous magnetic field of about 50,000 gauss. The loss of momentum flux in the gas flow is proportional to the magnetic impulse taken up to a point, where there seems to be a sudden adjustment of flow velocity. The position of this point is determined by the parameter $\sigma v B^2/P$. The higher this parameter, the earlier the interaction and the less its total effect. Moderately low values of the parameter produce the largest effects.

JETS OF A PERFECTLY CONDUCTING INVISCID GAS IN THE PRESENCE OF A MAGNETIC FIELD PARALLEL TO THE STREAM. Shigeki Morioka. Phys. Soc. Japan J., Aug., 1960, pp. 1516-1522. Analysis of two-dimensional and axially symmetric jet, based on linearized theory. When the jets are governed by the supersonic hyperbolic equation, so that the external disturbance does not propagate upstream into the nozzle, the fundamental equations and the boundary conditions are found to agree in their forms with those in the ordinary gas dynamic case, except for some parameters. However, when the surrounding flow is governed by the subsonic hyperbolic equation, the circumstance is somewhat different from the gas dynamic case, because disturbances in the surrounding flow propagate along the upstream characteristics. The structure of such a jet in the two-dimensional case is re-examined from the viewpoint of reflection and refraction of a weak plane shock wave incident upon an interface between two streams.

SOME ASPECTS OF NON-EQUILIBRIUM FLOWS. Raymond Sedney. US, BRL Rep. 1099, Mar., 1960. 37 pp. 13 refs. Study of the general features of nonequilibrium flow, especially vibrational relaxation, which is somewhat simpler than dissociation and ionization. Those aspects of two-dimensional and axisymmetric flow behind shock waves are examined analytically which yield significant information without requiring numerical solution of the governing equations. The thermodynamics of a vibrational relaxing gas are discussed. Crocco's theorem and the characteristic equations are derived. Then a simple method of obtaining the initial gradients of the flow variables behind a shock is shown. These gradients are used in discussing two particular flows. An exact solution for flow over a cusped body is obtained. Flow over a wedge near the tip and far from the tip is considered. It is found that far from the tip, a boundary-layer type phenomenon occurs.

ANALYSIS OF THE FLOW AND ENERGY SEPARATION IN A TURBULENT VORTEX. R. G. Deissler and M. Perlmutter. Internatl. J. Heat & Mass Transfer, Aug., 1960, pp. 173-191. 13 refs. Analysis of the velocity, temperature, and pressure distributions in a turbulent vortex with radial and axial flow. For making the calculations, the vortex is divided into a core and an annular region, each with a different uniform axial mass velocity, although the equations obtained are applicable to an arbitrary axial mass velocity distribution. Tangential velocity, temperature and pressure distributions, as well as curves for overall energy or temperature separation, are presented and compared with experiment. Using the analytical results, the causes of the energy separation are studied. It is concluded that the most important factor affecting the total temperature of a fluid element in a compressible vortex is the turbulent shear work done on or by the element.

Internal Flow

VERGLEICH DER DREIDIMENSIONALEN STRÖMUNGEN DURCH VERDICHTERLEITRÄDER MIT BEWEGTER NABE UND DURCH GERADE VERDICHTERGITTER. Georg Hubert. ZFW, Aug., 1960, pp. 226-243. 31 refs. In German. Investigation of an annulus formed by the compressor case and the hub behind the compressor stators. Speed of rotation of the hub, tip clearance of the cylindrical blades of NACA 8410-section, and the pitch of the blades were varied. Comparative tests on straight cascades of the same type, with stationary walls, as well as measurements of pressure distribution over the blades and flow pictures, were used complementarily. The results show the cascade flow not to be essentially influenced by the relative motion between blade tip and hub in the case of compressor stators. Furthermore, the results for stators with stationary hub are in good agreement with those for the straight cascades, provided the additional condition of radial equilibrium is taken into account in the former case. Loss coefficients, angles of outflow, static pressure rise, and axial velocities can, therefore, be estimated with reasonable accuracy for compressor stators using the values obtained from straight cascades.

REATTACHMENT OF A TWO-DIMENSIONAL, INCOMPRESSIBLE JET TO AN ADJACENT FLAT PLATE. C. Bourque and B. G. Newman. Aero. Quart., Aug., 1960, pp. 201-232. 21 refs. Application of Dodd's analysis to the Coanda deflection of a jet by a flat plate and comparison of the predictions with experimental evidence. Two approximate theories, developed from Dodd's analysis, are given for the mean pressure within the separation bubble, the position of reattachment, and the increase in volume flow from the slot. It is found that the flow becomes independent of both the length of the plate and the Reynolds number when these parameters are sufficiently large; the flow, scaled with respect to the width of the slot, is then uniquely determined by the plate inclination. The agreement with experiment is fairly satisfactory.

Jet Flaps & Wings

EMPIRICAL RELATIONSHIPS FOR JET-FLAP LIFT AND DRAG PREDICTION. D. J. Blakeslee. Aerospace Engrg., Nov., 1960, pp. 12-15. Presentation of empirical relations for the prediction of the lift and drag of unswept three-dimensional jet-flapped wings. Plotted data show that the equations organize lift and drag data with a consistency sufficient for design use. The principal innovation is that a thrust-recovery coefficient can be subtracted from the drag-coefficient equation to represent the so-called thrust recovery or induced thrust of jet flaps. This thrust recovery coefficient is simply related to jet-flap parameters. It is directly proportional to the momentum coefficient and varies approximately as a simple power of the flap angle.

Stability & Control

THE STABILITY OF THE SHORT-PERIOD MOTION OF AN AIRFRAME HAVING NON-LINEAR NORMAL FORCE AND PITCHING MOMENT CURVES. P. A. T. Christopher. Aero. Quart., Aug., 1960, pp. 255-268. Presentation of a method for the analysis of stability in second-order nonlinear systems by Poincaré's method of singular points in the phase plane. This method is then used to determine stability criteria for the short-period motion of an airframe. The results are then compared with those obtained by the application of quasi-linear stability theory.

EFFECT OF FIXED FORWARD FINS. G. S. Campbell. Aircraft Eng., Sept., 1960, pp. 271-274. Analysis of the effect of adding a small forward fin on the lift and center of pressure of a slender wing-body combination. The fin is assumed to discharge a trailing vortex which interacts with the main lifting surface. Design charts permit rapid estimation of lift loss and center of pressure movement for a delta wing plus body. At the lower angles of attack, the lift loss on the wing is approximately equal to the lift on the forward surface itself. Most of the lift is lost at the front of the wing, and so the wing center of pressure moves aft with the addition of the forward fin. Theoretical estimates are in general agreement with experimental results at Mach numbers 1.65 and 2.41.

Wings & Airfoils

THEORETICAL INVESTIGATIONS ON RING AIRFOILS. Johannes Weissinger. Karlsruhe Tech. Hochsch. Inst. Angew. Math. Rep. (AFOSR TN 60-343), Jan., 1960. 113 pp. 10 refs. Study of the effects of interference between a ring airfoil and a slender central body. Simple formulas for the lift and the pitching moment are derived from a more thorough theory by considerations taken from lifting line and three quarter point theory. Numerical results are given for ellipsoidal bodies. Two methods for computing the three-dimensional laminar boundary layer on ring airfoils are developed. The first is based on an expansion with respect to the angle of attack, the second is an itera-

tion procedure. In both methods a von Kármán-Pohlhausen procedure is used. The wall streamlines and the separation line are shown.

THE EFFECT OF THE GEOMETRY NEAR THE TRAILING EDGE ON THE ZERO-LIFT WAVE DRAG OF SLENDER WINGS. J. Weber. Gt. Brit., RAE TN Aero. 2662, Mar., 1960. 23 pp. Study of slender-body theory in which the zero-lift wave drag of bodies with a pointed nose depends on the cross-sectional area distribution and the geometry of the body near the trailing edge. The effect of the trailing edge geometry is determined for (1) wings with sharp trailing edge, (2) wings with blunt trailing edge, (3) wings with sharp trailing edge attached to a circular cylindrical body in mid-wing position.

LIMITATIONS OF THE SONIC AREA RULE. L. M. Sheppard. Aero. Quart., Aug., 1960, pp. 248-254. Analysis of test results for the sonic wave drag of sweptback, tapered wings, suggesting that the sonic area rule is applicable to thin wing and slender body combinations, provided that the product of the wing span/length ratio and the cube root of the thickness/chord ratio is less than unity. The wing span/length ratio was found to be a much more useful slenderness parameter than the aspect ratio. When the wing has a round-nosed section, theoretical considerations predict the existence of a so-called leading edge drag force varying with Mach number. It would be expected that such a wing would have the same sonic drag-rise as the equivalent body with an identical cross-section area distribution. Some test results do not confirm the drag-rise equivalent. It appears that the transonic drag-rise of the leading edge force is much greater than that predicted by theory. Tests on one basic wing-body combination, with different body cross-sectional shapes of the same area, suggest that the cross-sectional shape, of a smooth slender body, has no influence on the transonic wave drag of a configuration.

AEROELASTICITY

FLUTTER OF A DEFORMABLE ROCKET IN SUPERSONIC FLOW. Jerzy Kacprzynski and Sylwester Kaliski. 2nd ICAS Congr., Zurich, Sept. 12-16, 1960, Preprint. 14 pp. Presentation of an equation for the elastic vibration of a slender body in a supersonic flow, taking into account damping and axial forces. A general method of solution is proposed, consisting of a reduction in the original equation to a Volterra integral equation and applying the method of initial parameters. An approximate method of solution is also given, and results for the two types of computation examples of flutter velocity are given.

A METHOD OF SELFINDUCED ALLEVIATION OF AIRFRAME LOADS. F. Misztal. 2nd ICAS Congr., Zurich, Sept. 12-16, 1960, Preprint. 13 pp. Investigation into the possibilities of applying coupling of aileron deflections with wing bending deflections in order to reduce the variable aerodynamic wing load increments imposed by gusts and maneuvering. The purpose of the study is to increase considerably the safe fatigue life of basic wing structure components without apparent weight penalty. Some experimental results obtained from elastic wing model tests in a wind tunnel are presented and analyzed. The results of this analysis are discussed, in particular with reference to the structure fatigue conditions for an example of a typical gust load spectrum.

STEADY STATE DAMPED VIBRATIONS AND STABILITY OF A CLASS OF NONLINEAR DISCRETE SYSTEMS. S. T. Chow and P. R. Sethna. USAF WADC TR 59-543, Mar., 1960. 48 pp. Investigation of the steady state vibrations of a class of nonlinear discrete systems with an arbitrary number of degrees of freedom. Some special effects of the relations between the linear natural frequencies on the qualitative nature of the derived solutions are demonstrated. It is shown that if the linear natural frequencies do not possess certain relations, the system can be treated in a manner similar to that for a system of a single degree of freedom. The various solutions are then examined for their stability. Poincaré's theory of singularities in the phase plane is used to study the stability of those problems which can be treated in a manner similar to that for a single degree of freedom system. In all other cases the stability is examined by applying the Routh-Hurwitz criterion to a transformed set of equations. Solution for one specific problem is obtained and checked against those obtained from an analog type computer.

DAMPING OF RECTANGULAR PLATE VIBRATIONS. T. S. Lundgren, C. C. Chang, and Y. C. Whang. USAF WADC TR 59-544, Mar., 1960. 20 pp. Investigation of the effectiveness of two types of damping devices. First, an analysis is made of the effect of an impact type damping mechanism on a vibrating square plate. The force which the damping mechanism exerts on the plate is idealized as a series of impulses acting at the center of the plate. It is found that the device does not make a very effective damper. Then an analysis is made of the effect of a damping device on the vibrations of a rectangular plate. The damper considered is a free piston in a closed cylinder which is attached to the center of the plate. When the leakage through the gap between the piston and the cylinder is small, the piston is caused to oscillate on the "spring" of air in the cylinder. It is found that this device can effectively damp out the resonant mode of the plate vibration.

AIRPLANES

Control Systems, Automatic Pilots

CLOSED-LOOP FLIP-FLOP CONTROL SYSTEMS. Milton Rogers and George Shapiro. J. Aerospace Sci., Nov., 1960, pp. 841-853. Development of the basic concepts underlying the synthesis and analysis of closed-loop, flip-flop control systems of the electromechanical type. Closed-form analytical solutions are found which relate the various parameters in closed-loop, flip-flop

systems. The relationships among lead time, rise time, delay time, dwell time, and limit-cycle amplitude are determined as functions of inertia, aerodynamic damping, and available control moment. A strong dependence of system performance on aerodynamic damping is demonstrated. Damping is equivalent to a lead time and, when heavy aerodynamic damping is present, a lag in the feedback loop may be necessary for desired system performance.

Design

AIRCRAFT SHAPES AND THEIR AERODYNAMICS FOR FLIGHT AT SUPERSONIC SPEEDS. D. Küchemann. 2nd ICAS Congr., Zurich, Sept. 12-16, 1960, Preprint. 21 pp. 20 refs. Analysis, for a given flight range, to determine the geometry of supersonic aircraft which is defined by box sizes having certain relations between span and length into which the aircraft must fit. These boxes are always longer than they are wide and become narrower as the design Mach number goes up so that the aircraft lies always well within the Mach cone from its nose. Various layouts are then discussed, with suitable types of flow which not only give the required performance but are also acceptable for engineering purposes. The yawed wing, the swept wing-fuselage combination, and the slender wing are shown to offer potential solutions, each of these designed to have the same type of flow throughout its flight range. Slender wing aircraft are considered in more detail and some theoretical and experimental results are given.

ENGINES FOR SUPERSONIC AIR LINERS. R. R. Jamison and R. J. Lane. (RAeS 1,158th Lecture, London, Mar. 24, 1960.) RAeS J., Sept., 1960, pp. 507-530; Discussion, pp. 530-534. (Also in Bristol Siddeley J., Summer, 1960, pp. 100-104.) Study of the power-plant requirements for long range, high-speed transport aircraft considering turbojets with and without afterburners, combinations of turbojets and ram-jets, and ducted fans. Three supersonic speeds (Mach 2.0, 3.0, and 4.5) are chosen for comparison against the Mach 0.8 long-range jet transports. Emphasis is placed upon the interdependence of the engines and the airframe in the fields of aerodynamics, structures, installation, control, performance, and operation. To match the spectrum of engines, a corresponding variation of airframe properties is developed to suit the required mission over a range of values, primarily, of cruise speed and wing loading. The relative merits of different engine installations are finally assessed as the payload for the specified mission, assuming a constant gross weight for the aircraft. Each airframe-engine configuration has also to satisfy certain operational criteria such as take-off distance and approach speed on landing and, finally, nuisance factors such as engine jet noise and sonic boom are assessed and taken into account.

Landing, Landing Loads

A FLIGHT STUDY OF A POWER-OFF LANDING TECHNIQUE APPLICABLE TO RE-ENTRY VEHICLES. R. S. Bray, F. J. Drinkwater, III, and M. D. White. US, NASA TN D-323, July, 1960. 27 pp. OTS, $0.75. Presentation of a power-off landing technique developed for aircraft configurations having very low values of maximum lift-drag ratio. The initial phase of the pattern is a high-speed glide from altitude, aimed at a landmark short of the runway threshold. At a specified altitude and speed, a pull-out is made to a shallow flight path along which the aircraft decelerates to the touchdown point. Landings were made repeatedly within 600 ft. of a preselected touchdown point at airspeeds within ten knots of the desired value.

MATERIALS

High Temperature

MATERIALS FOR RE-ENTRY HEAT PROTECTION OF SATELLITES. Leo Steg. (ARS Semi-Annual Meeting, San Diego, June 8-11, 1959.) ARS J., Sept., 1960, pp. 815-822. 26 refs. Study of four types of materials suitable for ablation: (1) a material which gasifies but does not liquefy; (2) a material which reacts at its surface with the constituents of dissociated air; (3) a material which melts and vaporizes; and (4) a material which partially gasifies, the remaining material being removed by surface combustion. The result of a theoretical analysis of ablation for a typical satellite re-entry trajectory is presented together with some experimental data for materials of the four types: Teflon, graphite, quartz, and phenolic-nylon. The satellite re-entry environment was simulated in an electric arc driven tunnel. Comparison is also made between results in low heat transfer and high heat transfer test environments to illustrate differences in behavior between steady-state and nonsteady-state ablation. It appears that little ablation of the materials considered will occur during the ballistic re-entry of a blunt nonlifting vehicle from a satellite orbit. The selection of materials for heat protection can, therefore, be strongly influenced by other criteria.

MISSILE, ROCKET, & SPACE TECHNOLOGY

GENERAL RESEARCH IN FLIGHT SCIENCES - FLIGHT DYNAMICS AND SPACE MECHANICS. IX - MECHANICS PROBLEMS OF SPACEFLIGHT. W. E. Jahsman, G. B. Cline, Jr., H. V. Hahne, and W. Nachbar. Lockheed Aircraft Missiles & Space Div., vol. III, TR LMSD-288139, Jan., 1960. 101 pp. 20 refs. Discussion of the need for large-area, low-mass structures for use in orbiting and space vehicles. Certain static and dynamic problems associated with large-area, low-mass structures in the form of torustiffened membranes are treated in a preliminary fashion. It is found that this assembly, consisting of a circular membrane stretched by an inflated torus, has the desirable properties of light weight, relative ease in packaging, and unfurling. It also may be advantageous to reinforce the torus skin with high-strength filaments to keep the ratio of torus mass to membrane mass low. The dynamic problems treated included a study of the maneuvering "tacking" motions of a solar-sail spaceship and the conditions for stable

oscillations of a passive communications antenna. Unfurling of such structures may be accomplished through compressed air bottles or possibly by the use of dry ice which inflates the torus as it sublimes in orbit. Finally, some future topics of study to provide useful design information are suggested.

GENERAL RESEARCH IN FLIGHT SCIENCES - FLIGHT DYNAMICS AND SPACE MECHANICS. VIII - MASS CONSIDERATIONS IN RING-SUPPORTED SOLAR SAILS. W. E. Jahsman. Lockheed Aircraft Missiles & Space Div., vol. III, TR LMSD-288139, Jan., 1960. 14 pp. Study of the solar sail example of Tsu, for which the lower bounds to the mass of a ring to stiffen the solar sail are developed. It is found that a relatively large ring mass is required when the cross section is solid. Ring mass requirements are considerably reduced by the addition of massless stiffening spokes, or by the use of a ring with a hollow cross section. These results are further amplified by considering the solar sail efficiency, which is defined as the ratio of payload mass to total mass. An upper bound to the payload efficiency shows that this quantity decreases with increasing sail diameter.

PERFORMANCE AND DESIGN CONSIDERATIONS FOR MANEUVERING SPACE VEHICLES. L. W. Warzecha. Aerospace Engrg., Nov., 1960, pp. 18-23, 56-59 (ff.). 10 refs. Presentation of an analysis of the required degree of maneuverability for a variety of space missions, including return to the earth's surface. Design and performance penalties associated with high degrees of maneuverability are presented, with particular attention directed toward near-earth orbital flight. It is found that initial space maneuvers will be limited by propulsion requirements and will consist of simple rendezvous and intercept in near-earth orbital flight. Vehicle landing or recovery maneuvers will be required for landing at a preselected site from a low-altitude orbit on any chosen day, even though that site may be substantially far away from the satellite orbital plane. In most practical cases, recovery maneuvers will be performed more economically by semiballistic aerodynamic glide than by rocket-powered flight. Finally, it is concluded that a modular system for payload and mission flexibility can be achieved without significant weight or performance penalties.

EFFECTS OF JET BILLOWING ON STABILITY OF MISSILE-TYPE BODIES AT MACH 3.85. R. J. Salmi. US, NASA TN D-284, June, 1960. 17 pp. OTS, $0.50. Investigation of interference effects of a billowing jet on the forces and moments of two missile-type bodies. To simulate a rocket jet, pressurized nitrogen was exhausted from an annular sonic nozzle. The results indicate that for both models the stability parameter $dC_m/d\alpha$ (rate of change of pitching-moment coefficient with angle of attack) in the region of zero angle of attack was favorably influenced by the interference resulting from separation due to jet billowing. Schlieren photographs are presented that show the separation due to the jet billowing at various pressure ratios and angles of attack.

GENERAL RESEARCH IN FLIGHT SCIENCES - FLIGHT DYNAMICS AND SPACE MECHANICS. V - THE LOCAL ACCURACY OF DOPPLER ORBIT DETERMINATION. J. V. Breakwell. Lockheed Aircraft Missiles & Space Div., vol. III, TR LMSD-288139, Jan., 1960. 9 pp. Statistical analysis of the accuracy with which local orbital parameters can be determined from Doppler-frequency information during a single pass near a single station. The best-determined local orbital parameters are: time of closest approach, minimum slant range, and speed. Curves are obtained showing the accuracy of these three parameters for various minimum and maximum slant ranges, assuming that the difference points of the "observed" Doppler curve have independent errors.

Ballistics, Re-Entry

GENERAL RESEARCH IN FLIGHT SCIENCES - FLIGHT DYNAMICS AND SPACE MECHANICS. XI - SPIN-INDUCED FORCED RESONANT BEHAVIOR OF A BALLISTIC BODY HAVING STABLE NONLINEAR AERODYNAMIC PROPERTIES. J. S. Kanno. Lockheed Aircraft Missiles & Space Div., vol. III, TR LMSD-288139, Jan., 1960. 53 pp. Analysis of a ballistic body to determine the fundamental facets of the steady-state resonant behavior, as well as certain aspects of the transient behavior. Several modes of steady-state resonant behavior and corresponding transient behavior are shown to occur. Moreover, the manner of occurrence of these modes of ballistic motion is shown to be determined by a few elementary relationships. Two specific cases, typical monotonically "softening" and "hardening" C_m, are treated in detail to illustrate the application of the general results and to draw attention to the significant properties of the ballistic system.

GENERALIZED TABLES FOR THE CALCULATION OF TRAJECTORY CURVES FOR BODIES MOVING IN AIR. M. M. Currie. Canada, NRC Aero. Rep. LR-277, Apr. 1, 1960. 52 pp. Presentation of tables from which the cartesian coordinates of a trajectory can be readily derived for any initial conditions if the terminal velocity of the body is known.

EFFECT OF ECCENTRICITY OF THE LUNAR ORBIT, OBLATENESS OF THE EARTH, AND SOLAR GRAVITATIONAL FIELD ON LUNAR TRAJECTORIES. W. H. Michael, Jr., and R. H. Tolson. US, NASA TN D-227, June, 1960. 37 pp. 10 refs. OTS, $1.00. Comparison between lunar trajectories which were calculated by using the classic restricted three-body equations of motion, and lunar trajectories (with identical injection conditions) which were calculated by using equations of motion which include terms representing the additional effects. It is found that the oblateness of the earth can modify the trajectories in the vicinity of the moon by several hundred miles or more;

whereas, the eccentricity of the moon's orbit and the gravitational gradient of the sun are relatively less important and cause a difference in impact point of no more than one or two hundred miles along the lunar surface.

THEOREM OF IMAGE TRAJECTORIES IN THE EARTH-MOON SPACE. Angelo Miele. (XIth Internatl. Astron. Congr., Stockholm, Aug. 15-20, 1960.) Boeing Sci. Res. Lab. FSL Rep. 21, D1-82-0039, Jan., 1960. 20 pp. 14 refs. (Revised). Analysis considering the motion of a small vehicle in the earth-moon space under several hypothesis relative to the behavior of the earth-moon system. Two theorems associated with the relative motion are established: the irreversibility theorem and the theorem of image trajectories. The former theorem states that, if a trajectory is physically possible in the earth-moon space, the reverse trajectory is not physically possible. The theorem of image trajectories states that, if a trajectory is physically possible in the earth-moon space, the following image trajectories are also physically possible: (1) the image with respect to the plane which contains the earth-moon axis and is perpendicular to the axis of rotation of the earth-moon system, flown in the same sense as the original trajectory; (2) the image with respect to the plane which contains the earth-moon axis and the axis of rotation of the earth-moon system, flown in the opposite sense; and (3) the image with respect to the earth-moon axis, flown in the opposite sense. This theorem is of interest in the parametric study of lunar trajectories, since, once a basic set of trajectories is calculated, three additional sets can be obtained by simple transformation of coordinates.

GENERAL RESEARCH IN FLIGHT SCIENCES - FLIGHT DYNAMICS AND SPACE MECHANICS. VII - RESEARCHES IN INTERPLANETARY TRANSFER. J. V. Breakwell, R. W. Gillespie, and S. Ross. (ARS 14th Annual Meeting, Wash., Nov. 16-20, 1959, Paper.) Lockheed Aircraft Missiles & Space Div., vol. III, TR LMSD-288139, Jan., 1960. 42 pp. Presentation of a method by which interplanetary trajectories may be calculated rapidly and to a degree of accuracy suitable for design studies. By splitting the three-center problem associated with interorbital ballistic transfer into three one-center segments which overlap somewhat at their junctions, solutions may be readily found by machine iteration. Examples presented include velocity requirements for trips to and from Mars during the period from March, 1960 to April, 1961. Considering that the orbits of Earth and Mars are elliptical and mutually inclined, the Hohmann minimum-energy transfer criterion disappears, and the occurrence of several local minimum-energy trajectories is observed; this phenomenon is expected to be typical of all interplanetary orbit studies.

GENERAL RESEARCH IN FLIGHT SCIENCES - FLIGHT DYNAMICS AND SPACE MECHANICS. II - MINIMUM TRANSFER TIME FOR A POWER-LIMITED ROCKET. G. Leitmann. Lockheed Aircraft Missiles & Space Div., vol. III, TR LMSD-288139, Jan., 1960. 37 pp. 41 refs. Analysis considering the acceleration program leading to minimum transfer time for a power-limited rocket moving between prescribed positions and velocities in a constant gravitational field. It is found that flight must take place at maximum power and that the acceleration components are linear functions of time. The case of rectilinear transfer between positions of rest is treated in detail, and the results are compared with those previously obtained for a constant acceleration transfer.

ANALYSIS OF TRAJECTORY PARAMETERS FOR PROBE AND ROUND-TRIP MISSIONS TO MARS. J. F. Dugan, Jr. US, NASA TN D-281, June, 1960. 68 pp. OTS, $1.75. Presentation of charts for one-way transfers between Earth and Mars, that show velocity, time, and angle parameters as functions of the eccentricity and semilatus rectum of the Sun-focused vehicle conic. From these curves are obtained others useful in planning one-way and round-trip missions to Mars. The analysis is characterized by circular coplanar planetary orbits, successive two-body approximations, impulsive velocity changes, and circular parking orbits at 1.1 planet radii. For round trips, the mission time considered ranges from 130 to 1,000 days, while wait time spent in the parking orbit around Mars ranges from 0 to 454 days. Departure dates, one-way travel times, and individual velocity increments are presented for round trips requiring minimum total velocity increments. A set of 22 working charts for Earth-Mars trajectories is made available.

GENERAL RESEARCH IN FLIGHT SCIENCES - FLIGHT DYNAMICS AND SPACE MECHANICS. X - SPIN-INDUCED FORCED RESONANT BEHAVIOR OF A BALLISTIC BODY RE-ENTERING THE ATMOSPHERE. J. S. Kanno. Lockheed Aircraft Missiles & Space Div., vol. III, TR LMSD-288139, Jan., 1960. 31 pp. Analysis using a modified version of Leon's mathematical model to treat spin-induced ballistic behavior. The significant parameter of the forced resonant response is shown to be an index of the number of cycles of resonant excitation per unit change of altitude or aerodynamic environment. Furthermore, it is shown that for small values of this parameter, resonant excitation does not occur; consequently, the ballistic motion is essentially the response to a slowly spinning step input for the prescribed time-varying aerodynamic environment. On the other hand, for larger values of this parameter, resonant excitation becomes more apparent and the resulting motion, in turn, becomes larger. Finally, the important properties of the resonant response - the maximum angular displacement and the altitude at which it occurs - are summarized graphically as functions of the ballistic system.

GENERAL RESEARCH IN FLIGHT SCIENCES - FLIGHT DYNAMICS AND SPACE MECHANICS. XIII - EVALUATION OF THE MOTION AND AERODYNAMIC CHARACTERISTICS OF HIGH-FINENESS-RATIO RE-ENTRY CONFIGURATIONS. R. L. Nelson. Lockheed Aircraft Missiles &

Space Div., vol. III, TR LMSD-288139, Jan., 1960. 23 pp. Presentation of a method to analyze the aerodynamic information obtained from the X-17 missile during re-entry into the atmosphere. The equations which form the foundation of the method are described. Because of the inherent characteristics of the X-17 trajectory and mass characteristics of the vehicle, these equations are simplified forms of those developed in previous studies.

SIMILAR SOLUTIONS IN RE-ENTRY LIFTING TRAJECTORIES. Luigi Broglio. Roma U. Sch. Aero. Eng. Inst. Aero. Construc. Rep. SIAR 54 (AFOSR TN 60-678), Dec., 1959. 37 pp. Presentation of a method which leads to two exact equations valid at any altitude and in which the ballistic parameter is eliminated; a similarity law is thus obtained, relating bodies of different inertial and aerodynamic characteristics. Typical results are presented for an escape re-entry speed for a given acceleration peak of 10 g, and for constant lift/drag ratios. Similar results are also shown for an orbital re-entry speed.

LOS PROBLEMAS DE LA RE-ENTRADA. S. S. Aranguez. Ing. Aero. & Astron., Mar.-Apr., 1960, pp. 1-17. 11 refs. In Spanish. Study covering the dynamics of re-entry of a body into the atmosphere for the following cases: (a) direct interplanetary entry, (b) re-entry of satellites, and (c) re-entry of long-range missiles. Included are re-entry from a parabolic orbit or the direct entry, from a circular orbit, and from a parabolic and a circular orbit with nonzero lift. The heating problem is considered for direct entry (parabolic orbit) with zero lift, entry from circular orbit with zero lift, and entry with nonzero lift. The case of radiative equilibrium is also covered; the procedures for avoiding excessive heating during re-entry, including absorption, ablation, radiation, and transpiration are evaluated; and the materials suitable for re-entry are discussed.

Spacecraft

THE CONTRACTION OF SATELLITE ORBITS UNDER THE INFLUENCE OF AIR DRAG. I - WITH SPHERICALLY SUMMETRICAL ATMOSPHERE. G. E. Cook, D. G. King-Hele, and D. M. C. Walker. Royal Soc. (London) Proc., Ser. A, Sept. 6, 1960, pp. 224-249. 27 refs. Analysis using a perturbation method to determine the effect of air drag on satellite orbits of small eccentricity e (< 0.2), based on the assumption that the atmosphere is spherically symmetrical. Equations are derived which show (1) how perigee distance and orbital period vary with eccentricity as the orbit contracts, and (2) how each of these quantities varies with time. The equations of type (1) are nearly independent of the oblateness of the atmosphere. In all the equations, terms of order e^4 and higher are usually neglected. Results are presented graphically in a manner designed for practical use.

GENERAL RESEARCH IN FLIGHT SCIENCES - FLIGHT DYNAMICS AND SPACE MECHANICS. IV - ON THE ANOMALIES IN THE MOVEMENT OF THE PERIGEE DUE TO OBLATENESS AND AIR DRAG FOR CRITICAL VALUES OF INCLINATION. J. V. Breakwell. (Conf. on Orbit & Space Trajectory Determination, sponsored by the NASA, Mar. 13, 1959.) Lockheed Aircraft Missiles & Space Div., vol. III, TR LMSD-288139, Jan., 1960. 10 pp. Analysis of secular motion of the line of apsides due to second-order oblateness effects when the inclination is at 63.43°, at which value the first-order effect vanishes. When the inclination is in the vicinity of this value, the perigee is found to oscillate very slowly about either the northernmost or the southernmost point of its orbit, while the inclination itself simultaneously undergoes a slow oscillation with a first-order amplitude of first order in the oblateness. The effect of a small sideways drag due to a rotating atmosphere is also considered.

GENERAL RESEARCH IN FLIGHT SCIENCES - FLIGHT DYNAMICS AND SPACE MECHANICS. VI - ON THE MOTION OF A SATELLITE ABOUT A PLANET WITH ROTATIONAL SYMMETRY. C. M. Petty. Lockheed Aircraft Missiles & Space Div., vol. III, TR LMSD-288139, Jan., 1960. 42 pp. USAF-supported derivation of an approximate closed-form solution to the equations of motion of an earth satellite without restriction on the inclination angle or eccentricity. In order that the effect of "pear-shapeness" on a satellite orbit may be studied, the potential function contains the odd harmonic terms in addition to the ordinary oblateness terms.

SPACE RECONNAISSANCE. K. L. Sandefur. Aerospace Engrg., Nov., 1960, pp. 28-31, 60-62 (ff.) Survey of the state of the art in space reconnaissance considering both image-forming and non-image-forming sensors. Since the latter case involves sampling scalar-type fields in the immediate vicinity of the vehicle and is not bothered by slant range problems, the state of the art here seems adequate. In the image-forming sensors, it appears that photography provides more bits of information per pound of equipment than any other sensor. Infrared is limited by the optical collector and the detector size. Television is limited by the required optical system, but even more limited by CRT phosphor grain size. Radar is limited by the extremely large antenna requirements to obtain narrow beamwidths, and thus small resolution capability. Recommendations are made as to improving shape and contrast of the target, ground resolution, scale selection, and aperture and equipment size.

PHYSICS

Astrophysics

PLANETARY ASTRONOMY FROM SATELLITE-SUBSTITUTE VEHICLES. J. D. Strong, G. H. de Vaucouleurs, and Fritz Zwicky. USAF MDC TR 60-6, Mar., 1960. 159 pp., 143 refs. Study concerning the use of a balloon to carry a differential flux meter through the atmosphere to measure earth radiation. In addition, the use of a telescope

is described for planet and moon observation above atmospheric interference and for the observation of the sun and stars without the effect of an atmospheric filter. The optical and other technical problems of planetary astronomy, including modern photographic methods, are then discussed. The value of observation in the infrared spectral range from a location where nearly all of the atmospheric water vapor is below the observer is pointed out, as is the advantage of extremely high altitude observation of natural and artificial meteors.

Geophysics

IL PROBLEMA DEI RAGGI COSMICI IN ASTRONAUTICA. Marcello Rossi. Riv. Aero., June, 1960, pp. 903-933. In Italian. Study covering the problem of cosmic rays in astronautics. The nature and composition of cosmic rays are discussed along with their energy, intensity, and origin. The physical and biological effects of cosmic radiation are analyzed, including the effects on matter constituting the space vehicle and the particular effects on living cells of the human organism. A survey is made of the data on the structure of the atom, on protons and α particles, neutrons, electrons, and photons, and some protective measures are discussed.

POWER PLANTS

ELECTRIC PROPULSION FOR SPACE FLIGHT. W. R. Mickelsen. Aerospace Engrg., Nov., 1960, pp. 6-11, 36-52 (ff.). 34 refs. Discussion of mission analyses and vehicle design studies showing that electric propulsion promises high performance for space missions ranging from earth satellite orbit adjustment to manned space flight and deep space instrument probes. Considerable research has been done on the electric rocket engines classified into three general types: electrothermal rocket, plasma rocket, and ion rocket engines, and the status of these propulsion units is described. Problems common to most ion rocket design concepts are discussed for the three general types comprising the colloidal-particle, electron-bombardment, and contact-ionization ion rocket engines. Detailed mission analysis has shown that the nuclear rocket may be competitive with the electric rocket for probes and manned flights to the near planets. For satellite control and raising, lunar ferries, and deep space flight, the electric rocket appears to be clearly superior to the chemical rocket and to the nuclear rocket in its present form. The development of lighter weight electric power plants will make such comparisons more extreme since the power-plant weight is a prime factor in limiting electric spacecraft performance.

SATELLITE AND SPACE PROPULSION SYSTEMS. W. E. Moeckel, L. V. Baldwin, R. E. English, Bernard Lubarsky, and S. H. Maslen. US, NASA TN D-285, June, 1960. 47 pp. 12 refs. OTS, $1.25. Presentation of the results of a study of low-thrust systems for space and satellite propulsion undertaken in 1957 at the Lewis Research Center. Particular emphasis is placed on electric propulsion. After an introduction to the general characteristics of electric propulsion systems, some of the most promising electric power generators and thrust generators are reviewed. Electric propulsion systems are compared to chemical and nuclear rockets for satellite sustaining and orbit control, and for manned and unmanned missions to Mars.

Ram-Jet & Pulse-Jet

HYPERSONIC RAMJETS. D. L. Mordell and J. Swithenbank. 2nd ICAS Congr., Zurich, Sept. 12-16, 1960, Preprint. 15 pp. Discussion of hypersonic ram-jets using supersonic combustion, including the diffuser, combustor, and nozzle design problems. It is shown that unlike the conventional ram-jet, the supersonic combustion ram-jet imposes no insuperable problems as speed is increased even up to satellite levels. Performance estimates for the supersonic combustion ram-jet, using the best current data, suggest high propulsion efficiencies up to Mach 20, thus making it attractive for long-range high-speed aircraft, and for boosting large tonnages into orbit.

Rocket

COMPARISON OF LOCALIZED HEAT-TRANSFER RATES IN A LIQUID-OXYGEN - HEPTANE ROCKET ENGINE EMPLOYING SEVERAL INJECTION METHODS AND OXIDANT-FUEL RATIOS. R. F. Neu. US, NASA TN D-286, June, 1960. 39 pp. OTS, $1.00. Study of the effects of injection process and oxidant-fuel ratio upon local values of heat transfer, using a 1,800-lbs.-thrust oxygen-heptane rocket engine. Circumferential variations in local heat flux as high as 2:1 were observed. These heat-flux variations were influenced by the injector type and the oxidant-fuel ratio. Within the chamber, the longitudinal variations of heat flux were smaller, generally, than the circumferential variations. Each experimental case is explained individually in terms of such factors as injector spray pattern, spatial heat release, and patterns of hot gas flow.

SOLID PROPELLENT BURNING RATE THEORY. V. R. Gutman. Aircraft Eng., Sept., 1960, pp. 255-260. 26 refs. Study considering the roles of radiative heat transfer and a physical disintegrative mode of surface dissipation in a theory of propellant burning. The various theories that have been proposed are reviewed, and arguments are presented supporting the roles of the two burning mechanisms. It is believed that, although radiation which is in equilibrium with the propellant flame temperature may not be a dominant part of the gross energy feedback to the propellant surface, it is a contributing factor and cannot be ignored. Radiation beyond equilibrium - i.e., chemiluminescence - may be dominant in fuel-rich propellant flames, particularly in the presence of additives. Chemiluminescence and, to a lesser extent, thermal radiation, may supply energy for photolytic decomposition of propellant binders at rates beyond those associated with pyrolysis at the surface tempera-

ture. Once the surface is weakened by the above processes, mechanical disintegration can become a finite factor, reducing the total heat required at the surface as predicted by the simple heat balance.

RESEARCH, RESEARCH FACILITIES

Wind Tunnels

MEASUREMENTS OF TWO-DIMENSIONAL ZERO-LIFT INTERFERENCE OF VENTILATED BOUNDARIES AT SPEEDS UP TO SONIC. D. M. Rao and M. A. Ramaswamy. ZAMP, July 25, 1960, pp. 327-334. Investigation of the interference characteristics of typical slotted and perforated wind-tunnel walls in two-dimensional zero-lift flow, using a circular-arc profile as the test model. The influence on blockage interference of three slotted and two perforated walls with an area ratio ranging from 6% to 18% is studied at Mach numbers of 0.7 to 1.0. It is found that the slotted and perforated walls tested show almost identical mid-chord blockage interference variation with Mach numbers up to unity, in spite of the different geometric configurations. The experimental results are compared with available theories and it is concluded that for slotted boundaries, the theory of two-dimensional blockage interference appears adequate up to the model critical Mach number. For the perforated boundaries, however, the actual cross-flow/pressure-drop characteristics of the given boundaries must be used for calculating the interference, even at sub-critical Mach numbers.

AN OPTICAL BOUNDARY-LAYER PROBE. J. W. Daiber. J. Aerospace Sci., Nov., 1960, pp. 836-840. 10 refs. Navy-sponsored application of the schlieren-photomultiplier technique to obtain quantitative density measurements in the laminar boundary layer induced by a traveling shock wave in a shock tube. Tests were conducted at a Mach number of 1.58 so that the data could be compared with the exact theoretical solution tabulated by Mirels. The data obtained are in good agreement with the theory if the distance of the light beam above the floor of the shock tube is adjusted to fit the theoretical curve; this would not be necessary if a larger shock tube were used. It is shown that this technique is sensitive enough to detect changes in density that are only 0.006% of atmospheric density.

DESIGN AND OPERATION OF A CONTINUOUS-FLOW HYPERSONIC WIND TUNNEL USING A TWO-DIMENSIONAL NOZZLE. H. M. Schurmeier. NATO AGARDograph 38, May, 1959. 156 pp. 102 refs. Presentation of the summarized wind-tunnel design and operation experience accumulated at the JPL, concerning, particularly, the design of the hypersonic tunnel which will operate in the Mach number range of 5 to 9, with 21-in. by 21-in. test section and a two-dimensional nozzle. The main feature that distinguishes this tunnel from the conventional supersonic tunnels is that the air is heated before expansion in the nozzle to prevent air liquefaction in the test section. The other important difference is that considerably higher supply pressures are required to provide a reasonable unit Reynolds number and to avoid very low test section pressures which would require special instrumentation. The solution to these problems is discussed in some detail. Covered are such aspects as the tunnel uses and limitations; air supply - compressor plant, air heater, and shakedown operations; tunnel data including nozzle contour design, boundary layer estimation, diffuser aerodynamic design, cooling, mechanical design, and seals; instrumentation comprising calibration equipment, model support, force balances, manometers, schlieren system, heat transfer equipment, and data handling; and the design, operation, and performance of a scale model tunnel which is representative of the 21 in. hypersonic wind tunnel in all important mechanical and aerodynamic aspects.

STRUCTURES

STRUCTURAL ANALYSIS OF MULTI-HINGED CONTROL SURFACES. Appendix A - CONTINUOUS BEAM ON INDEPENDENTLY FLEXIBLE SUPPORTS. Appendix B - BEAM SUPPORTED BY A FLEXIBLE STRUCTURE. Appendix C - DETERMINATION OF SUPPORT FLEXIBILITY BY MEANS OF INFLUENCE FUNCTIONS. Appendix D - FLEXIBILITY OF A COMPOSITE STRUCTURE. E. Kosko. Canada, NRC Aero. Rep. LR-276, Mar., 1960. 160 pp. Presentation of an elastic small-deflection analysis of a control surface supported on a structure by means of three or more hinges. Effects of sympathetic flexure, of local bracket flexibility, and of angular deflection are taken into account. The existence is shown of an elastic hinge moment, quadratically dependent on the external loading. Application of the method is illustrated by numerical examples, which show that some secondary effects may become more critical than those of direct loading.

Cylinders & Shells

ANALYSIS OF FRAME-REINFORCED CYLINDRICAL SHELLS. I - BASIC THEORY. II - DISCONTINUITIES OF CIRCUMFERENTIAL-BENDING STIFFNESS IN THE AXIAL DIRECTION. III - APPLICATIONS. R. H. MacNeal and J. A. Bailie. US, NASA TN D-400; TN D-401; TN D-402, May, 1960. 57; 48; 136 pp. 12 refs. OTS, $1.50; $1.25; $2.75. I - Analysis of the state of stress in and near a reinforced frame subjected to concentrated loads and moments, and supported in a circular cylindrical shell. The theoretical approach enables tables of coefficients for the calculation of loads per in. in the shell, as well as loads and deflections in the frame, to be evaluated using a digital computer. II - The stress distribution in, and adjacent to, an externally loaded frame in a cylindrical shell is extended to include the effects of discontinuities of circumferential-bending stiffness in the axial direction. Such problems can be solved with the aid of a "transmission" matrix for a finite length of shell. A complete derivation for the elements of this matrix is given; it defines force-displacement relationships at the ends of the finite length of shell. III - Presentation of tables giving the loads and displacements in a flex-

ible frame supported by a circular cylindrical shell and subjected to concentrated radial, tangential, and moment loads. Additional tables give the loads in the shell.

CYLINDRICAL SANDWICH CONSTRUCTION DESIGN. Sidney Allinikov. USAF WADD TR 60-133, Feb., 1960. 276 pp. 14 refs. Presentation of a linear solution for the determination of the loads under which a cylindrical sandwich shell will buckle. The facings of the sandwich cylinder are treated as cylindrical shells and the core as an orthotropic elastic body. The method of solution is of interest in that it is of sufficient generality to be applied to many problems in sandwich analysis. The characteristic determinant that represents the solution to the problem is solved numerically. Curves which show how the buckling load changes as the parameters of the problem change are given.

STRESS ANALYSIS OF THIN-WALLED STRUCTURES WITH FLEXIBLE RING STIFFENERS, SUBJECTED TO CONCENTRATED LOADS. Andrzej Jaworski. Arch. Budowy Maszyn, No. 2, 1960, pp. 151-197. Presentation of a computation procedure which represents the interaction between the rings and the shell in the form of a Fourier series. The values of the amplitudes of the zero and first harmonics of the series are determined from the equilibrium conditions. The values of the remaining amplitudes, which are statically indeterminate quantities, are found from the Maxwell-Mohr equations. The application of the method of group unknowns, leading to five-term equations, enables a considerable simplification of the computational procedure.

ELASTIC INSTABILITY OF A CYLINDRICAL SHELL UNDER ARBITRARY CIRCUMFERENTIAL VARIATION OF AXIAL STRESS. P. P. Bijlaard and R. H. Gallagher. J. Aerospace Sci., Nov., 1960, pp. 854-858, 866. 13 refs. USAF-sponsored investigation to determine the buckling stress of a cylindrical shell for various circumferential distributions of axial stress. The development is based on small deflection theory, with finite difference techniques being applied to derive the general form of the governing algebraic linear homogeneous equations. The equations are cast in both the determinant and matrix forms, the latter being suitable for the commonly used matrix iteration solution. Numerical results are obtained by means of a high-speed digital computer for cases wherein the stress distribution is described by 32 circumferential elements. It is found that the buckling stress for pure bending, and for more complicated circumferential stress distributions as well, is not much higher than for uniform axial compression. Cases are indicated where small deflection theory is directly applicable.

Elasticity & Plasticity

A THEORY OF ELASTIC, PLASTIC, AND CREEP DEFORMATIONS OF AN INITIALLY ISOTROPIC MATERIAL. J. F. Besseling. Stanford U. Dept. Aero. Eng. SUDAER 78 (AFOSR TN 60-384), Dec., 1959. 36 pp. 10 refs. Presentation of stress-strain relations for an initially isotropic material, which is macroscopically homogeneous, but inhomogeneous on a microscopic scale. If the condition is imposed that all subelements of an element of volume are subjected to the same total strain, it is demonstrated that the inelastic stress-strain relations of the material show anisotropic strain-hardening, creep recovery, and primary and secondary creep due to the nonuniform energy dissipation in deformation of the subelements. Only quasi-static deformations under isothermal conditions are considered.

EFFECT OF BOUNDARIES ON WAVES IN A THERMOELASTIC SOLID: REFLEXION OF PLANE WAVES FROM A PLANE BOUNDARY. H. Deresiewicz. J. Mech. & Phys. Solids, Aug., 1960, pp. 164-172. Analysis considering the phenomena resulting from the incidence of plane thermoelastic waves on a plane, traction-free, thermally radiating boundary. It is found that an obliquely incident dilatational wave of either kind generates reflected waves of all three kinds, each of which (shear wave included) being dissipative and dispersive, the amplitudes diminishing with displacement normal as well as parallel to the boundary. An obliquely incident shear wave also gives rise to reflected waves of all three kinds, of which the shear wave, however, remains elastic, and the amplitude attenuation of the reflected elastic and thermal waves takes place only for displacement normal to the boundary.

Fatigue

TRAVELLING CRACKS IN ELASTIC MATERIALS UNDER LONGITUDINAL SHEAR. F. A. McClintock and S. P. Sukhatme. J. Mech. & Phys. Solids, Aug., 1960, pp. 187-193. USAF-supported extension of a solution for the stress field around the tip of a crack subjected to longitudinal shear and traveling with constant velocity in an elastic medium to the tensile case. As in the case of tensile cracks, the applied stress required for constant velocity is lower for higher crack velocity, and there is a critical velocity approximately 0.6 times that of the shear wave velocity above which the crack will branch. Similar stress levels are found using two different fracture criteria: the Griffith energy criterion and the criterion of critical shear strain averaged over a critical area.

SOME KINETIC CONSIDERATIONS OF THE GRIFFITH CRITERION FOR FRACTURE. I - EQUATIONS OF MOTION AT CONSTANT FORCE. II - EQUATIONS OF MOTION AT CONSTANT DEFORMATION. J. P. Berry. J. Mech. & Phys. Solids, Aug., 1960, pp. 194-216. 10 refs. Derivation of the equations of motion, without reference to the criterion for fracture, and determination of the effect of the approaching Griffith condition by adjustment of a dimensionless parameter. It is concluded that the details of the motion of the crack are determined by the stress condition existing at the point of fracture, and that the observed critical

stress is grater than that given by the Griffith criterion. The equations of motion for cracks in tensile and cleavage samples are then derived, assuming that the deformation of the sample is maintained constant after the critical condition for fracture has been attained. It is shown that the behavior of cracks in tensile samples depends on their initial size and that large cracks are more stable than small cracks.

Plates

A SIMPLE METHOD OF MATRIC STRUCTURAL ANALYSIS. V - STRUCTURES CONTAINING PLATE ELEMENTS OF ARBITRARY SHAPE AND THICKNESS. Bertram Klein. J. Aerospace Sci., Nov., 1960, pp. 859-866. Analysis using basic equilibrium and force-displacement equations, most of which contain definite integrals. The plate elements may be of any shape, have any thickness variation, and the stresses in the elements may vary in a complex pattern. There need not be any edge members attached to the plates. Since, in general, the shapes and thickness of the plate elements are arbitrary, a simple numerical integration scheme is used to evaluate these integrals. Numerous numerical examples are worked out to illustrate the mechanics of the method and the accuracy attainable.

PLASTIC INTERACTION CURVES FOR ANNULAR PLATES IN TENSION AND BENDING. P. G. Hodge, Jr., and R. Sankaranarayanan. J. Mech. & Phys. Solids, Aug., 1960, pp. 153-163. ONR-sponsored analysis to determine the maximum load-carrying capacity of an annular plate acted upon by a uniform normal load over its surface and a constant tensile load around its outer edge. The material is rigid/plastic and satisfies the Tresca yield condition of maximum shearing stress with its associated plastic potential flow law. Elementary solutions are given for pure bending and pure tension, and the closed bounds for the interaction curve of combined bending and tension are established. Other possible conditions are considered and general formulas are obtained for the interaction curve bounds.

PLASTIC BENDING OF A WORK-HARDENING CIRCULAR PLATE WITH CLAMPED EDGE. Chintsun Hwang. J. Aerospace Sci., Nov., 1960, pp. 815-820, 840. Study of the plastic bending of a rigid, work-hardening circular plate with clamped edge and under distributed transverse load. The plate material is assumed to follow the yield condition of von Mises and to harden isotropically. The incremental stress-strain law is used. The possibility of partial unloading of the plate material during the loading cycle is investigated. The problem is represented as two sets of two simultaneous differential equations corresponding to the loading and unloading portions of the plate material, which are solved using a digital computer.

AN ELECTRICAL ANALOGUE SOLUTION FOR THE STRESSES NEAR A CRACK OR HOLE IN A FLAT PLATE. Appendix - CALCULATION OF DIRECT AND SHEARING STRESSES FROM THE STRESS FUNCTION. S. C. Redshaw and K. R. Rushton. J. Mech. & Phys. Solids, Aug., 1960, pp. 173-186. Application of an electric analog method to solve the biharmonic equation that is used to determine the elastic stresses near a crack. Problems concerning both simply and multiply connected regions are solved by the method and, where a comparison between the experimental results and existing analytical solutions is possible, the agreement is good. The advantages and limitations of the method are discussed, and the desirability of extending the method for the determination of the stresses after plastic yielding has occurred, is emphasized.

PASMO PŁYTOWE Z ŻEBRAMI JEDNOSTRONNYMI. Ryszard Ganowicz. Rozprawy Inżynierskie, No. 2, 1960, pp. 323-342. 11 refs. In Polish, with summaries in English and Russian. Analysis to determine the mechanical values for a freely supported plate strip strengthened by ribs on one side. The solution is obtained with the assumptions and on the basis of the relations obtained by Pflüger. A system of three equations for the displacements u, v, w of a point of the middle surface is reduced to one equation for the displacement function. Assuming the solution in the form of a trigonometric series, expressions are obtained which can be written in closed form. A numerical example is worked out and the results are compared with those from model tests, showing good agreement with the theoretical solution.

DESIGN CHARTS FOR TRANSIENT TEMPERATURE AND THERMAL STRESS DISTRIBUTIONS IN THERMALLY THICK PLATES. J. S. Przemieniecki. Aero. Quart., Aug., 1960, pp. 269-284. Analysis of plates with an arbitrary variation of the heat transfer coefficient and the adiabatic wall temperature of the boundary layer. The method is based on repetitive applications of the exact analytical solution to a unit triangular variation of the adiabatic wall temperature and a constant heat transfer coefficient. The actual variation of the adiabatic wall temperature is represented as a series of straight lines, while the heat transfer coefficient is approximated by a step function. The temperature distribution through the plate is separated into linear and "self-equilibrating" temperature distributions to facilitate thermal stress calculations; these distributions are presented graphically.

Plates With Holes

ANALYSIS OF STRESS CONCENTRATIONS AT REINFORCED HOLES IN INFINITE SHEETS. W. H. Wittrick. Aero. Quart., Aug., 1960, pp. 233-247. Derivation of equations for a wide range of holes of practical importance, including circles, ellipses, and squares, triangles, and rectangles with rounded corners. Two loading cases are treated: the first corresponds to uniform tensions at infinity in directions parallel and perpendicular to the axis of symmetry of the hole, and the second

to uniform shear at infinity in these directions. Superposition of these basic loading cases enables the stresses to be determined for any uniform state of stress at infinity.

Thermal Stress

HEAT CONDUCTION AND THERMAL STRESSES IN A SOLID HAVING UNEQUAL SPECIFIC HEATS. E. W. Parkes. Stanford U. Dept. Aero. Eng. SUDAER 90 (AFOSR TN 60-320), Feb., 1960. 23 pp. Study of the problem of separation for the heat conduction and stressing problems in thermoelastic analyses. This division can only be justified if the specific heat at zero stress for the material is closely equal to that at zero strain. An analysis is made of the transient temperature distribution and thermal stresses in a solid subjected to one-dimensional heat flow and various kinds of stress-inducing restraints, when the specific heats are unequal. Allowance is made for the stress terms in the heat conduction equation (which are ignored when the analysis is divided) and for the variation of specific heat with temperature. It is concluded that the errors introduced by the conventional approach, although not entirely negligible, are not such as to justify the labor involved in the more correct analysis.

THERMODYNAMICS

Combustion

SOME CONTRIBUTIONS TO LAMINAR FLAME THEORY. Gregorio Millan and Ignacio Da Riva. 2nd ICAS Congr., Zurich, Sept. 12--16, 1960, Preprint. 23 pp. USAF-sponsored analysis of a simplified flame model with two unique chemical species, reactants and products. The effect of the diffusion, as well as the influence of the concentration in the reaction rate, are taken into account, but not that of activation energy. Three cases are considered, the first being heat loss localized at the stabilizer. It is shown that the two velocities of Hirschfelder reduce to only one by means of a choice of an adequate parameter; the apparent contradiction between Spalding's experimental results and the theoretical conclusions is pointed out. For flames with distributed heat losses, the two velocities of Spalding reduce to only one by varying slightly the boundary conditions at the hot limit, both when an ignition temperature at the cold boundary is assumed, as well as when the porous stabilizer of Hirschfelder is used. Finally, the effect of a dilution of the mixture produced by the lateral diffusion of the active species is considered.

UNTERSUCHUNGEN ÜBER DEN MASSENAUSTAUSCH HINTER FLAMMENHALTERN. Gert Winterfeld. (WGL Meeting, Hamburg, Oct. 16, 1959.) ZFW, Aug., 1960, pp. 219-225. In German. Study of the mass transport processes between the inner and outer flow behind bluff body flameholders. A method of deadbeat measurement is developed which permits the determination of the mean residence time of the gas particles in the recirculation zone by measuring the concentration of a test gas blown into the wake of the bluff body. Tests were done in cold flow and covered circular plates and cones of different cone angles. The results are in agreement with an equation containing the residence time, velocity of flow from initial direction, and the dimension of the bluff body. Further influences to be taken into consideration are the shape of the bluff body, the blockage ratio, the Reynolds number, and the turbulence of flow from initial direction.

RICERCHE SULLA STABILIZZAZIONE DELLE FIAMME IN CORRENTI AD ALTA VELOCITA. II. Federico Filippi, Laura Fabbrovich-Mazza, and Salvatore Calandrino. (16th Natl. Aero. Congr., Pisa, Oct. 5--8, 1959.) L'Aerotecnica, Feb., 1960, pp. 25-33. 16 refs. In Italian. Description of an investigation to determine the possibility of extending the stability limits of bluff-body flame holders. Small amounts of auxiliary gases (methane, propane, air, nitrogen) were injected through a single 5-mm. rod flame holder in a two-dimensional burner supplied by premixed methane/air and propane/air mixtures. The results show that the injection of fuel shifts the stability limits toward leaner mixtures, while the injection of air shifts these limits toward richer mixtures. With fuel injection, the maximum blow-off velocity decreases with increasing injection rates. An extension of the current Zukoski hypothesis is proposed.

CONTRIBUTION A L'ETUDE DE LA COMBUSTION DANS LES FUSEES A LITHERGOL OU HYBRIDES. André Moutet and Marcel Barrère. 2nd ICAS Congr., Zurich, Sept. 12-16, 1960, Preprint. 33 pp. 16 refs. In French. Study of the combustion of solid hypergolic fuels in the presence of a liquid oxidizer injected into the chamber. The analyzed phenomena are related to the ignition, steady burning, and combustion stability. The ignition is studied by means of special devices which measure the ignition delay evaluated as function of the nature of the fuel and the oxidizer. The steady regime is characterized by the value of the ablation rate of the solid fuel in a hot oxidizing flow. This ablation rate is evaluated as function of the engine working parameters, and the obtained laws explain the operating principles of hybrid rockets. Also included is a study of the stability of such a system.

Heat Transfer

THE STEADY AND TRANSIENT FREE CONVECTION BOUNDARY LAYER ON A UNIFORMLY HEATED VERTICAL PLATE. R. J. Goldstein and E. R. G. Eckert. Internatl. J. Heat & Mass Transfer, Aug., 1960, pp. 208-218. 14 refs. Application of a Zehnder-Mach interferometer to study the thermal boundary layer of a plate immersed in water. The steady state boundary layer, as well as its transient development from an initial state at rest and with uniform temperature to steady state condition, was investigated when a step function in the power input to the plate was applied. Results for the steady state runs agree well with the results of an analysis by Sparrow and

Gregg. The transient runs indicate that the temperature field in the fluid develops in the same way as for heat conduction into a semi-infinite solid. After a short transition period, the steady state condition is reached. The boundary layer grows with time in such a way that it increases at first with increasing time, reaches a maximum, and decreases again until it settles to a steady state value.

INFLUENCE COEFFICIENTS FOR RADIATION IN A CIRCULAR CYLINDER. E. W. Parkes. Stanford U. Dept. Aero. Eng. SUDAER 92 (AFOSR TN 60-415), Mar., 1960. 11 pp. Calculation of a table of influence coefficients from which the distribution of absorbed radiation in a long circular cylinder having any distribution of emitted radiation can readily be determined. Lambert's law of diffuse emission and reflection is assumed, and the coefficient of absorptivity is supposed constant. A table of functions for the distribution of reflected radiation after each reflection up to the tenth is also given, so that the results can be compared with non-Lambertian systems.

APPLICATION OF VARIATIONAL METHODS TO THE THERMAL ENTRANCE REGION OF DUCTS. E. M. Sparrow and R. Siegel. Internatl. J. Heat & Mass Transfer, Aug., 1960, pp. 161-172. 13 refs. Presentation of a variational method for solving eigenvalue problems that arise in connection with the analysis of convective heat transfer in the entrance region of ducts. Consideration is given to both situations where the temperature profile depends upon one cross-sectional coordinate (circular tube) or upon two cross-sectional coordinates (rectangular duct). The variational method is illustrated and verified by application to laminar heat transfer in a circular tube and a parallel-plate channel, and good agreement with existing numerical solutions is attained. Then, application is made to laminar heat transfer in a square duct.

VTOL & STOL

LES TROMPES APPLIQUEES AU VOL VERTICAL, VERS L'AILE-TROMPE. Jean Bertin. Tech. & Sci. Aéronautiques, Mar.-Apr., 1960, pp. 79-91. In French. Discussion of the general characteristics of the jet effect and derivation of the important parameters, particularly those giving lift effects. These effects are considered for application to flying platforms and to configurations incorporating the jet in a wing structure together with deflecting flaps. The jet used for vertical flight is compared with other lifting systems.

WIND-TUNNEL TESTS OF A CIRCULAR WING WITH AN ANNULAR NOZZLE IN PROXIMITY TO THE GROUND. R. K. Greif, M. W. Kelly, and W. H. Tolhurst, Jr. US, NASA TN D-317, May, 1960. 37 pp. OTS, $1.00. Investigation to determine the effects of forward speed and ground proximity on the vertical thrust of an annular nozzle exhausting from the lower surface of a thin circular wing. Lift, drag, and pitching moment data are presented with nozzle airflow over a range of altitude, nozzle pressure ratio, free-stream dynamic pressure, and wing angle of attack. Pressure distributions on the wing lower surface and on the ground are also included. The results from tests at zero forward speed show that the model experienced thrust augmentation near the ground. The effect of the forward speed on vertical thrust depended on the distance of the nozzle from the ground. Near the ground, forward speed could increase or decrease the thrust, depending on the conditions of altitude, forward speed, and jet momentum considered. Far from the ground, the effect of forward speed was favorable and always increased thrust. With the moment center located at the center of the wing, this configuration was statically unstable longitudinally for all conditions of altitude and forward speed.

AN EXAMINATION OF HANDLING QUALITIES CRITERIA FOR V/STOL AIRCRAFT. S. B. Anderson. US, NASA TN D-331, July, 1960. 51 pp. 27 refs. OTS, $1.50. Study to define handling qualities criteria for V/STOL aircraft. With the current military requirements for airplanes and helicopters as a framework, modifications and additions have been made for conversion to V/STOL requirements using flight results and pilots' comments from a limited number of VTOL and STOL aircraft, BLC equipped aircraft, and flight simulators. Also included is a discussion of the reasoning behind suggested V/STOL requirements and of the areas where existing information is inadequate and further research is required.

WIND-TUNNEL INVESTIGATION OF A SMALL-SCALE MODEL OF AN AERIAL VEHICLE SUPPORTED BY DUCTED FANS. L. P. Parlett. US, NASA TN D-377, May, 1960. 24 pp. OTS, $0.75. Investigation of the longitudinal-stability and pitching moment characteristics, and the power requirements of a simplified model of an aerial vehicle supported by ducted fans. The model has two ducted fans, both fixed with respect to the airframe with their axes of revolution vertical for hovering flight. Tests on the basic model in the tandem and side-by-side configurations indicated that the pitching moment and tilt angle required for trim at forward speeds were undesirably large. Turning vanes placed in the slipstream of the forward duct of the tandem configuration reduced both the pitching moment and tilt angle, but probably increased the power required.

INVESTIGATION OF THE AERODYNAMIC CHARACTERISTICS OF A COMBINATION JET-FLAP AND DEFLECTED-SLIPSTREAM CONFIGURATION AT ZERO AND LOW FORWARD SPEEDS. K. P. Spreemann and E. E. Davenport. US, NASA TN D-363, May, 1960. 72 pp. OTS, $2.00. Investigation undertaken to provide data useful in analyzing the manner in which augmentations may combine at low forward speeds and the effect of ground proximity. The aerodynamic characteristics of a semispan wing equipped with a 38.5%-chord sliding flap partially immersed in the slipstream of two propellers are studied. A jet of air was ejected over the knee of the flap through a momentum-coefficient range from zero to about 1.0. It is noted that large losses in lift were encountered at low forward speeds for values obtained within ground proximity compared with values obtained out of ground proximity.

the 7,135 to 7,985 mc. frequency range and relays radar search and surveillance data by a narrow microwave beam, virtually eliminating interception by an enemy.

O Pomekhoustoichivosti Raznostno-Diskretnogo Metoda Peredachi Informatsii. V. M. Baikovskii. *Avtom. i Telemekh.*, Mar., 1960, pp. 344–358. In Russian. Study of the potential noise stability of incremental coding and comparison with the noise stability of pulse-code and delta modulation.

Pomekhoustoichivost' Chastotnoi Teleizmeritel'noi Sistemy pri Slabykh Impul'snykh Pomekhakh. Iu. I. Chugin. *Avtom. i Telemekh.*, Jan., 1960, pp. 93–105. In Russian. Study of the effect of weak pulse interferences of arbitrary duration on a frequency receiver, and application of analytical results to calculate the noise stability of frequency telemetering system.

Transmission Lines

Coupled Leaky Waveguides. II—Two Parallel Slits in a Cylinder. S. Nishida. *IRE Trans., AP Ser.*, July, 1960, pp. 354–360. USAF-sponsored research.

Wave Theory

Some ELF Phenomena. E. T. Pierce. (*Conf. on Propagation of ELF Radio Waves, Boulder, Jan. 25, 1960.*) *J. Res., Sect. D - RP*, July–Aug., 1960, pp. 383–386. 13 refs. Discussion of properties of the electric and magnetic fields in natural extremely low frequency (ELF) phenomena. The ELF fluctuations in the electric field are then treated from two aspects: (1) the electromagnetic changes associated with atmospherics and (2) the electrostatic variations in atmospheric electricity.

Natural Electromagnetic Energy Below the ELF Range. W. H. Campbell. (*Conf. on Propagation of ELF Radio Waves, Boulder, Jan. 25, 1960.*) *J. Res., Sect. D - RP*, July–Aug., 1960, pp. 409–411. 10 refs. Review of some studies on the characteristics of natural electromagnetic fields which are encountered as measurements are made to frequencies lower than those dominated by the sterics slow tails. In particular, magnetic field oscillations with periods of 5 to 30 sec. are discussed. Experimental data and new development in the relation of magnetic field micropulsations to the pulsating aurora are presented.

Possible Application of the System Loss Concept at ELF. K. A. Norton. (*Conf. on Propagation of ELF Radio Waves, Boulder, Jan. 25, 1960.*) *J. Res., Sect. D - RP*, July–Aug., 1960, pp. 413, 414. Presentation of a brief description of the possible application of the system loss concept at extremely low frequencies. A method for allowing for the effect of external noise levels is outlined.

The Compatibility Problem in Single-Sideband Transmission. K. H. Powers. *IRE Proc.*, Aug., 1960, pp. 1431–1435. USAF-sponsored study of the relations that must hold between the envelope and the phase of a single-sideband wave. The study is made under the assumption of simultaneous amplitude and phase modulation of a carrier.

Mode Theory and the Propagation of ELF Waves. J. R. Wait. (*Conf. on Propagation of ELF Radio Waves, Boulder, Jan. 25, 1960.*) *J. Res., Sect. D - RP*, July–Aug., 1960, pp. 387–404. 48 refs. Discussion of the mode theory of propagation of electromagnetic waves at extremely low frequencies (ELF) (1.0 to 3,000 cps). The field is represented as a sum of modes, and approximate formulas are presented for the attenuation and phase constants.

Rasprostranenie Zvukovykh i Infrazvukovykh Voln v Prirodnykh Volnovodakh na Bol'shie Rasstcianiia. L. Brekhovskikh. (*3rd Internatl. Acous. Congr., Stuttgart, Sept., 1959.*) *Uspekhi Fiz. Nauk*, Feb., 1960, pp. 351–360. 12 refs. In Russian. Discussion of the propagation over long distances of sound and infrasound waves in natural wave guides. Covered are acoustic wave guides in the ocean and in the atmosphere, as well as the variation in shape of the acoustic impulse.

Nelineinye Iavleniia v Plazme, Nakhodiashcheisia v Peremennom Elektromagnitnom Pole. I, II. V. L. Ginzburg and A. V. Gurevich. *Uspekhi Fiz. Nauk*, Feb.; Mar., 1960, pp. 201–246; 393–428. 133 refs. In Russian. Survey of the general theory of nonlinear effects in plasma surrounded by a variable electromagnetic field. The study covers the effect of a uniform electric field $E = Ee^{i\omega t}$ on the nonrelativistic and classical plasma, and the propagation of radiowaves in the ionosphere, taking into account the effect of nonlinearity, nonlinear interaction of modulated radiowaves (cross modulation), and experimental results on the cross modulation in the ionosphere.

The Use of Polarization Fading of Satellite Signals to Study the Electron Content and Irregularities in the Ionosphere. C. G. Little and R. S. Lawrence. *J. Res., Sect. D - RP*, July–Aug., 1960, pp. 335–346. 15 refs. Presentation of a procedure for using the Faraday-rotation fading of a satellite radio signal to measure the ionospheric electron content per unit

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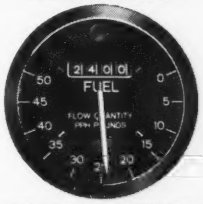

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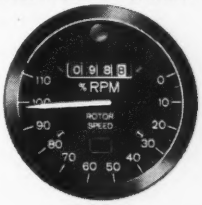

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column up to the height of the satellite. Results based on observations of 1958 Delta 2 are presented.

Relation of Turbulence Theory to Ionospheric Forward Scatter Propagation Experiments. A. D. Wheelon. *J. Res., Sect. D - RP*, July–Aug., 1960, pp. 301–309. 32 refs. Study of the relation of turbulence theories to radio measurements on VHF ionospheric forward scatter circuits. The single scattering description of the electromagnetic response of electron density irregularities and the corresponding transmission expression are evaluated. The several theories for turbulent mixing of the electron density are summarized.

Equipment

Water Vapor Pump Study. J. R. Malcolm. *USAF WADC TR 59-254*, Feb., 1960. 127 pp. Presentation of the results of an investigation to determine the feasibility of utilizing a water vapor pump to lower the vapor pressure of a water heat sink to obtain water boiling temperatures in the 40° to 70°F. and the 120° to 160°F. range, for application in aircraft covering the speed range from Mach 1.5 to 12 and altitude range from sea level to 150,000 ft.

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L'Equipement Electrique du Boeing 707, II. H. Lanoy. *Docaéro*, May, 1960, pp. 39–52. In French. Detailed description of the electric equipment of the Boeing 707 jet transport, including the grouping of alternators and coupling by busbars, control of a.c. distribution, and d.c. systems, as well as systems for power supply from external sources.

New Solenoids Take 2000 g, 1850 deg F. *Space/Aeronautics* July, 1960, pp. 91, 92, 94, 96, 98. Discussion of the problems encountered and the solutions found in the design of a solenoid which can withstand accelerations of 2,000 *g* without shaft rotation and still work afterwards, and in the design of a solenoid which can perform properly despite shaft temperatures as high as 1,850°F.

Hydraulic & Pneumatic

Verschiedene Auslegungsmöglichkeiten bei Hydraulikanlagen. A. Mesthé. *Luftfahrttechnik*, June 10, 1960, pp. 181–184. In German. Survey of fundamental principles of aircraft hydraulic circuits, and discussion of various solutions offered for the operation of main aircraft elements, such as landing gear, brakes, steering system for taxiing, flaps, equipment used when on the ground, and servocontrols.

Fuels & Lubricants

Fuel Qualities for High Performance Aircraft. R. I. Oza. *Aero. Soc. India J.*, Feb., 1960, pp. 13–16. Discussion of the jet fuel family presently used commercially, including a comparison of their respective characteristics, and a study of the requirements for fuels which are to be used in engines which fly in the region of Mach 3–5. For this type of engine, the saturated cyclic hydrocarbons are seen as the most satisfactory solution with respect to high hydrocarbon ratio, thermal stability, low temperature properties, vapor pressure, density, availability, and economy.

Rocketdyne Tests New Solid Propellants. E. J. Bulban. *Av. Week & Space Tech.*, Aug. 8, 1960, pp. 80–85. Discussion of the characteristics of the new carboxy-terminated linear polybutadiene Flexadyne propellants, of some solid rocket motor research programs, and some metalworking techniques which play a part in these programs.

Polymer Chemistry Leads to Advanced Solid Propellants. *Thickol Astronaut*, No. 1, 1960, pp. 14–16. Presentation of data on the newly developed and currently tested C-12 polysulfide fuel binder which displays superior properties of low temperature flexibility and resistance to ageing at high temperature.

Fluorine Solid Propellants. Milton Farber. *Astronautics*, Aug., 1960, pp. 34, 40, 42. Discussion of the fundamentals of solid propulsion and of the properties of fluorocarbons and fluorohydrocarbons as propellants.

Gliders

Some Notes on Seeking New Methods of Sailplane Lift-Drag-Curve Measuring. Vlastimil Pokorny. (*OSTIV 7th Congr., Lesno, Poland, June, 1958.*) *Schweizer Aero-Rev.*, Mar., 1960, pp. 189–192.

Instruments

Selection of Vacuum Gauges for Altitude Measurements. *CEC Recordings*, 2nd Quart., 1960, pp. 19–21. Discussion of the various types of vacuum gages and the principles involved, including the McLeod, Pirani, thermocouple, ionization, Philips (discharge), and radiation gages. Their application is also given.

Accelerometers

Better Accelerometers Off the Shelf. R. J. Cohen. *Prod. Eng.*, Sept. 5, 1960, pp. 54, 55, 57. Discussion of the types, performance, and applications of the instruments for testing acceleration, vibration or shock, or for use as speed controls, remote leveling devices, and rotational balances.

Flight Instruments

Ein Funkhöhenmesser grosser Genauigkeit. A. Gayffier and R. Labrousse. *Luftfahrttechnik*, June 10, 1960, pp. 190–192. In German. Discussion of the operating principles of the CSF radio altimeter AM 220 H, and description of the mode of operation of its various stages along with design specifications.

Flow Measuring Devices

Capacitance Change Indicates Liquid Levels. T. L. Greenwood. *Electronics*, Aug. 19, 1960, pp. 66, 67. Presentation of the design of a liquid-level measuring system for calibrating turbine-type rate-of-flow meters.

Gyroscopes

On the Stability of a Gyroscopic System. I. Z. Pirogov. (*Prikl. Mat. i Mekh.*, Nov.-Dec., 1959, pp. 1134–1136.) *PMM—Appl. Math. & Mech.*, No. 6, 1959, pp. 1623–1626. Translation. Analysis using Liapunov's second method to investigate the problem of stability of motion of a gyroscopic stabilizing system installed on a ship performing complex maneuvers. Roitenberg's method is used to construct Liapunov's function for variation equations.

Die Bewegungsgesetze des Raumkompasses. W. Bauersfeld. *Ing.-Arch.*, vol. 27, No. 6, 1960, pp. 365–371. In German. Analysis of the behavior of a variant of Anschütz's directional gyro. It is shown that, theoretically, this gyro is completely insensitive to accelerations.

Ustoichivost' Giroskopa, Imeiushchego Vertikal'nuiu Os' Vneshnego Kol'tsa, pri Uchete Sukhogo Treniia v Osiakh Podvesa. V. V. Krementulo. *Prikl. Mat. i Mekh.*, May–June, 1960, pp. 568–571. In Russian. Survey of previous calculations and study of the stability of a gyroscope for the case of vertical external-ring axis, taking into account the dry friction along the support axes.

Three-Axis Rate Gyro; Reliability Evaluation Techniques. J. A. Hogg and R. G. Stokely. *Missile Des. & Devel.*, Aug., 1960, pp. 24, 25, 53, 54. Discussion of the reliability evaluation techniques used on the Titan 3-axis rate gyro package.

CRIG—A New Gyro for Autopilot Use in High-Speed Boats, Light Aircraft, Short-Range Missiles and Target Drones. Sahag Dardarian. *Kearfott Tech. News Bul.*, May-June, 1960, pp. 14–18. Presentation of the design features and principles of operation of the single degree of freedom gyro which senses and integrates rate by means of a capacitor. The output is a signal proportional to the sum of the attitude and rate.

Pressure Measuring Devices

Design and Tests of Aerodynamic Static Pressure Compensators for Four Service Aircraft. F. O. Smetana. *USAF WADC TR 59-383*, May, 1959. 37 pp. Presentation of design considerations and test results for aerodynamic static pressure compensators suitable for nose boom mounting on four service aircraft.

Stress & Strain Measuring Devices

Measuring Strain to 1000°F. R. L. Hannah and A. M. Kinan. *Instruments & Control Systems*, July, 1960, pp. 1166–1168. Presentation of a method of compensating for the "apparent strain" signal caused by temperature changes.

Laws & Regulations

The Air Carrier's Liability in Cases of Unknown Cause of Damage in International Air Law. I. Finn Hjalsted. *J. Air Law & Commerce*, Winter, 1960, pp. 1–28. 147 refs. Study of the air carrier's contractual as well as delictual liability in international air law in cases where the cause of damage remains completely or partially unknown.

Machine Elements

Bearings

The Optimum Thrust Tilting-Pad Bearing. Leif Floberg. *Chalmers Tek. Högskolas Handlingar, No. 231*, 1960. 23 pp. 10 refs.

Measurement of Surface Waviness of Rolling-Element Bearing Parts. Olof Gustafsson and Ulrich Rimrott. *SAE Summer Meeting, Chicago, June 5–10, 1960, Preprint 195C.* 13 pp. Discussion of the concept of waviness the influence of waviness on the performance of the bearing, and methods of waviness testing and measuring.

How to Predict Oscillation Life of Ball and Roller Bearings. Thomas Barish. *Mach. Des.*, Sept. 1, 1960, pp. 113–116.

Ultra High Speed Ball Bearings; Their Selection and Application. L. W. McKee. *Missile Des. & Devel.*, Aug., 1960, pp. 18–20, 22, 23, 53. Discussion of the factors to be considered in the selection and application of bearings for service at speeds in excess of 600,000 DN (D = bore in mm., N = r.p.m.).

The Two-Groove Journal Bearing, Considering Cavitation. Leif Floberg. *Chalmers Tek. Högskolas Handlingar, No. 232*, 1960. 32 pp. 11 refs.

Short Journal Bearings Subjected to Dynamic Loads. M. N. Özdaş. *Istanbul Tek. U. Bul.*, vol. 12, 1959, pp. 99–114. 12 refs. Analysis extending the short bearing theory to include the case of dynamically loaded bearings. Preliminary results are included.

Gears & Cams

Rocket Motor Gear Tooth Analysis (Hertzian Contact Stresses and Times). E. K. Gatcombe and R. W. Prowell. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59-A-256.*) *ASME Trans., Ser. B - EI*, Aug., 1960, pp. 223–229; Discussion, C. N. Epstein and J. K. Morris, pp. 229, 230. Navy-supported research.

Maintenance

Automatic Tester Keeps B-58 Mission-Ready. S. P. Kaprielyan. *Aircraft & Missiles*, Aug., 1960, pp. 50–52. Discussion of Bendix' mobile tape-controlled test set which checks the flight control system on a go-no-go basis in a few hours, isolating any malfunction to the smallest flight-line replaceable unit.

The Repair of DC-8 Pneumatic Ducts. *Douglas Serv.*, May-June, 1960, pp. 1–15.

Producing Flying Hours by Planned Aircraft Maintenance. I. J. Gregory. *SLAE J.*, May, 1960, pp. 3–15. Discussion of the methods adopted by British European Airways to produce 200,000 flying hours per year in the form of serviceable aircraft by means of a planned maintenance system.

Materials

Rocket-Motor Cases. I. F. J. Wilkinson and C. L. M. Cottrell. *Aircraft Prod.*, Aug., 1960, pp. 313–319. 14 refs. Discussion of the mechanical properties required for steels used in rocket-motor case manufacture. The effect of alloy additions in obtaining high-tensile strength is reviewed and some high-strength steels are described. The adverse effects on performance of sulphur, phosphorus, and other impurities present in the steel are discussed, with particular reference to weldability, impact strength, and ductility.

Surface Effects on Materials in Near Space. F. J. Clauss. *Aerospace Engrg.*, Oct., 1960, pp. 16–19, 56, 58, 59, 62. 13 refs. Discussion of problems associated with the behavior of surfaces of materials in space, including passive temperature control, effect of space environment on surface stability, and wear and seizure of rubbing or sliding surfaces.

Ceramics & Ceramals

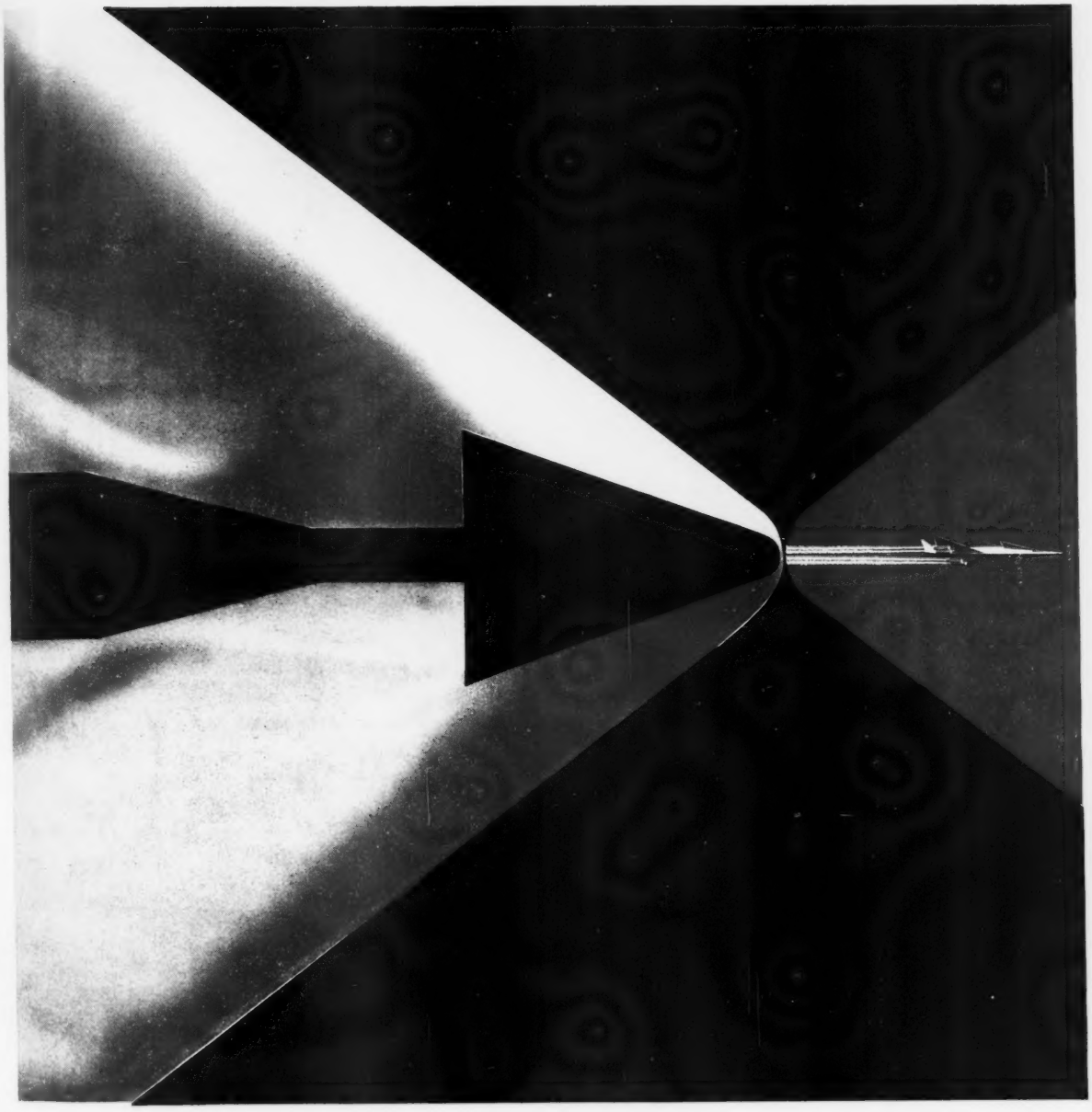
Refractory Inorganic Materials for Structural Applications. Appendix I—**Thermal Shock Theories.** Appendix II—**State of the Art Survey on Foamed Ceramics.** Appendix III—**Literature Review.** H. A. Pearl, J. M. Nowak, J. C. Conti, and R. J. Urode. *USAF WADC TR 59-432*, Feb., 1960. 142 pp. 97 refs. Study of 35 refractory material systems by means of room temperature modulus of rupture, impact, and thermal shock tests.

Investigation of Sinterable Powders and Properties of Beryllia Ceramics. J. E. Johnson, A. K. Smalley, and W. H. Duckworth. *USAF WADD TR 60-108*, Apr., 1960. 19 pp.

Corrosion & Protective Coatings

Development of Protective Coatings for Refractory Metals. C. G. Goetzel, P. S. Venkatesan, and R. F. Bunshah. *USAF WADC TR 59-405*, Feb., 1960. 50 pp. 44 refs. Investigation of the feasibility of protecting tungsten against oxidation at 1,650°C. (3,000°F.). A complex coating formed by diffusion from successive deposits of chromium, silicon, chromium, and rhodium, which protects tungsten wire against oxidation in stagnant of flowing air at temperatures up to 1,650°C. for short periods of time, is discussed and experimental results are included.

Protective Coatings for Refractory Metals. C. G. Bergeron, A. L. Friedberg, R. C. Anderson, V. E. Bradford, D. M. Maroney, and R. W. Bohl. *USAF WADC TR 59-526*, Jan., 1960. 44 pp. 45 refs. Presentation of experimental results



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showing that oxygen-free atmospheres, but not high vacuum conditions, are required for the successful application of ceramic coatings on tungsten. Vitreous-bonded coatings consisting of zircon and low expansion refractory glass, combinations of silicide and vitreous-bonded coatings. SiO coatings, and flame-sprayed coatings are investigated.

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Ionospheric Electron Densities for Washington D. C., Panama, Talara, and Huancayo for October-November-December, 1958. E. R. Schmerling. *Penn. State U. IRL Sci. Rep. 136* (*USAF GRD TN 60-497*), Aug. 1, 1960. 90 pp.

The Effect of Turbulence and Magnetic Field on Electron Density Fluctuations in the Ionosphere. I. D. Howells. *J. Fluid Mech.*, Aug., 1960, pp. 545–564. Study of Dungey's model and results to determine in more detail the irregularities of electron density and to take into account diffusion due to electron and ion partial pressures.

A Preliminary Study of Sunrise Effects in the D-Region. A. C. Aikin. *Penn. State U. IRL Sci. Rep. 133* (*USAF GRD TN 60-491*), June 1, 1960. 28 pp. 11 refs.

Optics

Consideration of a Surveying Telescope Objective in the Initial Stage of Optical Designing, Taking Third Order Aberrations Into Account. I. Ujváry. *Periodica Polytech., Eng. Ser.*, No. 3, 1959, pp. 247–254. Presentation of a study of the variations experienced by the focal lengths of the converging and diverging lenses in teleobjective-type surveying telescope objectives depending on optical tube-length and separation of the lenses. In order to reduce aberrations, large partial focal lengths and small Petzval sums have been aimed at. An apparently satisfactory solution has been obtained and illustrated by a numerical example.

Power Plants

Meet the Hyperjet. R. L. Maxwell. *Remarks*, Summer, 1960, pp. 9–11. Discussion of the modes of operation, ground and flight tests, and applications of the hyperjet which integrates rocket and ram-jet in a single power plant.

Space Power Needs Urgent. *Missiles & Rockets*, Aug. 15, 1960, pp. 22, 23, 29. Discussion covering the trend toward solar mechanical systems in preference to nuclear units, components and subsystems of a typical solar mechanical power system, and considerations and requirements in the development of such a unit.

The Prospects of MHD Power Generation. Leo Steg and G. W. Sutton. *Astronautics*, Aug., 1960, pp. 22–25, 82–86. 20 refs. Discussion of problem areas in magnetohydrodynamic power generation, including the difference between a gaseous and a metallic conductor and its engineering implications, the Hall effect, power generation experiments and generator design approaches, the major factors decreasing the efficiency of an MHD generator, and application areas.

Plasma Propulsion. S. W. Kash. *SAE Summer Meeting, Chicago, June 5–10, 1960, Preprint 185B.* 11 pp. Discussion of the fundamentals of steady-state and pulsed plasma accelerators.

Solar Mechanical Engine. Ch. D. LaFond. *Missiles & Rockets*, Aug. 15, 1960, pp. 24, 25, 28. Discussion of the design, specifications, and design problems of the biggest solar mechanical engine currently under development by the USAF.

Atomenergi För Raketer. Hans von Ubisch. *Astronautik*, No. 1, pp. 30–44. 10 refs. In Swedish. Discussion of the feasibility of nuclear rocket propulsion, based mostly on the recent

monograph by Bussard and DeLauer, and examination of the possibility and purpose of the photon rocket.

Experimental Studies with Small-Scale Ion Motors. C. R. Dulgeroff, R. C. Speiser, and A. T. Forrester. *ARS J.*, Aug., 1960, pp. 761–763. USAF-supported study of cesium surface ionization sources. In mass utilization studies it was found that 70 per cent of the cesium used reached the collector as high-energy ions, and over 90 per cent was ionized at the ionizer.

High Altitude Testing of Propulsion Systems. B. H. Goethert and Delbert Taylor. *ZFW*, July, 1960, pp. 202–211. Study of stringent operating conditions required of a ground-test facility in conducting high-altitude tests of propulsion systems and their associated components. Included is a discussion of various techniques which may be used to augment the performance of existing facilities sufficiently to meet the ever-increasing requirements of current and future high-performance propulsion systems.

Jet & Turbine

Gasturbinenentwicklungen in der Bundesrepublik Deutschland. Karl Leist. *BWK*, June 5, 1960, pp. 267–276. 29 refs. In German. Historical survey of the development of gas turbines, covering a description of small gas turbines and jet engines, as well as the current research on flow, turbulence, and cavitation problems, optical stress investigations, and temperature distribution measurements.

Lycoming Gas Turbines. *AHS Newsletter*, July, 1960, pp. 2–8. Survey of Lycoming gas turbine models, including design features, as well as Lycoming development and production facilities and services.

Current Problems in Aero Engine Design. E. S. Moult. *(13th Louis Blériot Memorial Lecture, Paris, Mar. 2, 1960.) de Havilland Gazette*, June, 1960, pp. 86–89. Discussion of the effects of different factors on thrust and economy in supersonic transports, and problems concerning high temperature engines.

Versuchsaufgaben bei der Entwicklung von Turbinentriebwerken. H. G. Münzberg and O. David. *Luftfahrttechnik*, June 10, 1960, pp. 171–180. In German. Discussion of experimental problems in the development of turbine power plants. Emphasis is placed on aerodynamic, thermodynamic, and performance tests, and a brief description of the respective test-bed equipment designed for this purpose is given.

Bristol Siddeley's Fans. *Flight*, Aug. 12, 1960, pp. 210–212. Discussion of Bristol Siddeley's effort to develop a new family of double-flow gas turbines—the ducted-fan engines.

Measuring the In-Flight Thrust Variable Nozzle Jets. R. J. Patton. *Space/Aeronautics*, Aug., 1960, pp. 89, 90, 92–99 (ff.). Discussion of three techniques tried during B-58 in-flight thrust determination.

An Approximate Investigation of the Effect of Boundary-Layer-Control Pumping on Powerplant Performance. T. F. Kirkwood. *J. Aerospace Sci.*, Oct., 1960, pp. 799, 800. Analysis showing that turboprop engines suffer a greater loss due to pumping than turbojet engines, particularly at low flight speeds. At low flight speeds, duct loss tends to be the largest contributor to the suction drag coefficient.

Rocket

X-15's Turbopump Arrangement Minimizes Temperature Effects. *Des. News*, Aug. 1, 1960, pp. 6, 7. Discussion of the design, particularly the relative mounting of the basic elements, of the X-15's new 50,000-lb.-thrust rocket engine. Description of the basic system is included.

Conformal Transformation of a Solid Propellant Grain with a Star-Shaped Internal Perforation Onto an Annulus. H. B. Wilson, Jr. *ARS J.*, Aug., 1960, pp. 780, 781. Army-sponsored research.

Rocket Heat-Transfer Literature. R. W. Graham, G. Morrell, R. D. Turnacliff, J. H. Robinson, K. G. Englar, R. G. Deissler, D. R. Bartz, H. N. McManus, Jr., and E. E. Soehngen. *ASME Trans., Ser. C – HT*, Aug., 1960, pp. 155–169. 191 refs. Presentation of a literature survey covering the following: rocket-engine heat sources, rocket cooling techniques, nozzle wall materials, variable fluid-property effects, predictions of thermal properties, and flow separation and acoustic effects.

VR 3—Sweden's First Pump Fed Liquid Rocket Engine. Björn Ankarswärd. *Astronautik*, No. 1, 1960, pp. 21–29. Description of the VR 3 pump fed liquid rocket engine that uses a propellant combination 82 per cent hydrogen peroxide and jet engine fuel. The engine delivers 4,900 lbs. thrust at sea level, and—although developed as a booster for aircraft—can also be used in missiles and sounding rockets.

Stress-Strain Equations for Case-Bonded Solid Propellant Grains. Ch. H. Parr. *ARS J.*, Aug., 1960, pp. 778, 779. 10 refs. Army-sponsored development of equations expressing elastic stresses and strains in a three-material, composite, hollow, circular cylinder representing a case-bonded propellant grain, liner, and motor case for loading conditions consisting of internal pressure, arbitrary radial temperature gradient, and volumetric changes.

Vernier Engines for Control, Guidance, Acceleration, Braking. K. R. Stehling. *Space/Aeronautics*, Aug., 1960, pp. 49–51. Review of applications and design techniques for vernier engines of all types in missiles and spacecraft. Performance requirements and development problems are discussed.

Aerodynamic Heating Charts for Solid Propellant Rocket Motors. G. R. Guinn. *ARS J.*, Aug., 1960, pp. 776–778. Presentation of solutions for transient temperatures in a semi-infinite composite solid when the heat input is approximated by a fifth-degree polynomial of time. These solutions are presented as charts from which the temperature history at several locations in a typical liner-propellant combination can be computed for a given aerodynamic heating input.

The E-D Nozzle. G. V. R. Rao. *Astronautics*, Sept., 1960, pp. 28, 29, 50, 51. Discussion of the expansion-deflection nozzle which, for the same static thrust as a conventional bell nozzle, offers both reduced size and weight and improved thrust performance at low altitudes.

Plug-Nozzle Flexibility. Kurt Berman and Bruce Neuffer. *Astronautics*, Sept., 1960, pp. 30, 31, 52. Description of various configurations of the plug-nozzle and discussion of their possible applications.

Turbopump Key to New X-15 Engine. William Beller. *Missiles & Rockets*, Aug. 15, 1960, pp. 33, 34. Discussion of the unit which insures controllability and adequate fuel flow for Thiokol's XLR99 power plant, including a description of engine, turbine, and pump characteristics.

Variable-Thrust Rocket Engines and Their Modes of Operation. M. W. Cardullo. *J. Aerospace Sci.*, Oct., 1960, pp. 793–795. Analysis of the various methods of achieving variable operation of liquid rocket engines. These include the following methods to vary thrust: (1) stepped chambers, (2) propellant throttling, (3) throat throttling, and (4) combination of throat and injection throttling.

Production

Minuteman in the Making. J. P. Kushnerick. *Aircraft & Missiles*, Sept., 1960, pp. 17–19. Description of the first-stage assembly sequence for the Minuteman missile.

Die Fertigung der Hauptrotorblätter der "Alouette" II SE 3130. *Luftfahrttechnik*, June 10, 1960, pp. 185–189. In German. Survey of the development in the construction of helicopter rotor blades by Sud-Aviation, and description of the manufacturing and test equipment. Also presented are details on the manufacture of main-rotor blades of the Alouette, describing the general structure of the blade, the various production stages, and the procedure for dynamically balancing the finished blade.

Metalworking

New Nitriding Process for Increased Wear and Fatigue Resistance. J. H. Shoemaker and George Bidigare. *SAE Summer Meeting, Chicago, June 5–10, 1960, Preprint 178B.* 13 pp. Description of the Tufftride process which involves the immersion of the specimen in a specially formulated molten salt bath. The process is applicable to low-carbon, alloy, stainless tool steels, heat resistant steels, and grey, alloy, nodular or ductile, malleable and pearlitic irons.

Beryllium Research for Development in the Area of Casting. F. A. Crossley, A. G. Metcalfe, and W. H. Graft. *USAF WADC TR 59-500*, Feb., 1960. 92 pp. 32 refs. Presentation of the results of an investigation involving the following: (a) X-ray determination of the direction of columnar growth in cast beryllium, (b) consumable arc melting, (c) reported allotropy by thermal analysis, (d) grain-refining inoculants, and (e) application of vibration to cast beryllium for grain refinement.

Electrohydraulic Forming. L. W. Herchenroeder. *Aircraft Prod.*, Aug., 1960, pp. 302, 303. Study of the electrical circuits for the application of the electrohydraulic forming process.

Titanium Alloys Hot-Formed on Gas-Heated Stretch Press Dies. C. J. Morris, Jr. *Space/Aeronautics*, Aug., 1960, pp. 117, 118, 122–126 (ff.). Description of a method of hot forming, based on the use of natural gas burners and applied in shaping titanium alloys for B-58 nacelle panel skins.

Analysis of Power Spinning of Cones. Appendix—Transformation of Co-Ordinate Systems and Mathematical Description of Toric Part of Roller. B. Avitzur and C. T. Yang. *(ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59—A-173.) ASME Trans., Ser. B - EI*, Aug., 1960, pp. 231–244; Discussion, Serope Kalpakcioglu, pp. 244, 245. Presentation of the mathematical description of the geometry of the cone, the roller, and the spinning operation.

The Applications of Radioisotopes in Machining Operations. J. H. Tolan. *SAE Summer Meeting, Chicago, June 5–10, 1960, Preprint 181C.* 7 pp. Discussion including the fundamentals of the process and its applications.

Machining Thin Discs. II—Development in Balanced Contour Turning at Rolls-Royce. H. J. Pearson. *Aircraft Prod.*, Aug., 1960, pp. 304–312. Discussion of the design and operation of a large and versatile machine for profiling Rolls-Royce Conway engine rotor discs.

Radioisotopes Broaden the Approach to Machining Studies. Marko Paliobagis and E. J. Krabacher. *SAE Summer Meeting, Chicago, June 5–10, 1960, Preprint 181A.* 21 pp. 23 refs. Discussion of the use of radioisotopes in the form of irradiated cutting tools to investigate the problems of tool wear as influenced by the numerous machining parameters.

Advanced Steel Cutting Speeds Atlas Production. *Space/Aeronautics*, Aug., 1960, pp. 71, 72, 74, 76. Description of several cutting methods used in shaping steel parts and fixtures for the Atlas missile, including powder burner cutter for stainless steel and the crank press for cutting bulkhead gore skins.

Determination of Cutter Trajectories for Contoured Turbine Buckets. R. G. DeBiase. *(ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59—A-111.) ASME Trans., Ser. B - EI*, Aug., 1960, pp. 200–203; Discussion, W. W. Kuyper, p. 204. Presentation of a definition of the turbine-bucket surface in terms of unequally spaced cross sections along the length of the part. An interpolating procedure is employed to define the entire surface with properly faired transitions between the specified cross sections.

Electron-Beam Processing. *Aircraft Prod.*, Aug., 1960, pp. 282–286. Discussion of the Zeiss electron-beam process for working very hard materials. Advantages of its use in welding and drilling are presented.

Numerical Control Gaining. S. P. Kaprielyan. *Aircraft & Missiles*, Sept., 1960, pp. 48–51. Discussion of some methods of numerical control for machining, used in the aerospace industry.

Fusion Welding of Beryllium. T. J. McDonald, N. F. Eaton, and D. B. Wright. *Brit. Welding J.*, July, 1960, pp. 441–450. Discussion of equipment and conditions for experimental tungsten-arc inert-gas autogeneous fusion welding of beryllium.

Brazing and Soldering of Beryllium. R. W. Keil, G. S. Hanks, and J. M. Taub. *(AWS 41st Annual Meeting, Los Angeles, Apr. 25–29, 1960.) Welding J. Res. Suppl.*, Sept., 1960, pp. 406-s–410-s. Discussion of the methods investigated, equipment and material used, and experimental results from the initial developmental investigation of the brazing and soldering of beryllium.

Beryllium Joining WADC Sponsored Program. E. M. Passmore. *USAF WADC TR 59-695, Pt. II*, Apr., 1960. 113 pp. 25 refs. Investigation of methods for joining beryllium plates and rods (involving braze welding, fusion welding, and pressure welding) to develop improved methods for applications at both room and elevated temperatures. It is found that braze welding with silver filler metal and pressure welding without filler offer the most promise as useful joining techniques for beryllium.

Spot Welding of Wrought HK31A, HM21A, and ZE10A Magnesium Alloys. Lloyd Lockwood. *(AWS Natl. Fall Meeting, Pittsburgh, Sept. 26–29, 1960.) Welding J. Res. Suppl.*, Sept., 1960, pp. 369-s–378-s. Presentation of information of the newer wrought magnesium-base alloys using three-phase, low-frequency, converter-type spot-welding equipment.

Weldability of Aluminum Casting Alloys with 5086 Wrought Aluminum Alloys. M. S. Orysh and I. G. Betz. *(AWS 41st Annual Meeting, Los Angeles, Apr. 25–29, 1960.) Welding J. Res. Suppl.*, Aug., 1960, pp. 342-s–351-s. Investigation using Almag 35, Al-7% Mg, 214, 356, 42B and Al-7% Mg-3% Zn. The results of the study show that thin weldments are more apt to have a very poor joint efficiency due to lack of fusion if welded without a backing strip.

Studies on Repair Welding Age-Hardenable Nickel-Base Alloys. W. J. Lepkowski, R. E. Monroe, and P. J. Rieppel. *(AWS Natl. Fall Meeting, Pittsburgh, Sept. 26–30, 1960.) Welding J. Res. Suppl.*, Sept., 1960, pp. 392–s–400-s. Investigation to develop and evaluate techniques of repair welding that would prevent failure during subsequent heating to temperatures where ductilities are low.

Investigation of Weldability of Ultra-High-Strength Steels. M. J. Albom and Ch. C. Titherington. *(AWS Natl. Fall Meeting, Pittsburgh, Sept. 26–30, 1960.) Welding J. Res. Suppl.*, Sept., 1960, pp. 385-s–391-s. Investigation to produce full-penetration welds meeting a minimum yield-strength requirement of 220 kc. Four steels are welded with five commercial filler wires.

Propellers

Variable Camber Prop Studied for VTOL. Barry Tully. *Av. Week & Space Tech.*, Aug. 15, 1960, pp. 98, 99, 101. Discussion of the tandem variable camber propeller, including planned development programs, performance of the test model, and design potential. It is pointed out that the variable camber propeller presents a solution to the conflicting lift/drag requirements of take-off and cruise. In addition to VTOL applications, the use of the variable camber propel-

ler to increase the on-station time of airborne early warning aircraft is considered.

D. H. Propellers for the Tyne. M. E. L. Evans. *The Aeroplane & Astronautics*, Aug. 5, 1960, pp. 159–161, cutaway drawing. Discussion of the design, operation, and safety features guarding against overspeeding of the de Havilland variable pitch feathering and reversing propeller designed for the Rolls-Royce Tyne.

Reliability

Predicting Reliability. M. I. Kaufmann and R. A. Kaufman. *Mach. Des.*, Aug. 18, 1960, pp. 178–184. 12 refs. Presentation of three methods for designing for required performance and life: the "standard" method, the method using rating factors, and relative-utility evaluation.

Linear Contrasts. I. Ch. H. McCall, Jr. *Ind. Quality Control*, July, 1960, pp. 19–21. 11 refs. Discussion of four techniques in analysis of variance study and their merits for detecting specific significant differences existing among a set of k-means.

A Nomogram for Upper Confidence Limits to Percent Defective. A. L. Hardester and G. L. Burrows. *Ind. Quality Control*, July, 1960, pp. 16–18. Presentation of a nomogram for the estimation of the long-run failure rate, the estimation of the size of the experiment for a specific confidence limit, and for the setting of nonparametric statistical tolerance intervals. The application of the chart is illustrated for each case.

Research, Research Facilities

Ob Avtokolebaniiakh Platformy Dinamicheskogo Stenda. G. F. Miroshnichenko. *Avtom. i Telemekh.*, Mar., 1960, pp. 293–300. In Russian. Determination of some characteristics of the motion of a platform which is part of a single-axis dynamic stand with an induction motor having a hollow rotor used in constructing and adjusting automatic pilots. Conditions for the onset of natural oscillations in the presence of dry friction in mountings are found. The dynamic system is represented by a two-dimensional mathematical model leading, in one case, to Milne's equation and, in the other, to that of Lienard.

Flight Testing

Giant for Air Cargo. *CEC Recordings*, 2nd Quart., 1960, pp. 3–5. Discussion of the flight test program and equipment of the CL-44 propjet long-range transport.

Wind Tunnels

Supersonic-Wind-Tunnel Air-Drying-System Design. T. W. Macios. (*ASME Annual Meeting, Atlantic City, Nov. 29–Dec. 4, 1959, Paper 59–A–161.*) *ASME Trans., Ser. B - El*, Aug., 1960, pp. 277–281. 15 refs. Discussion of criteria for air-drying-system design. Various types of systems are examined and a method of drying-system selection is presented.

La Soufflerie Pilote à Arc Bref de l'O.N.E.R.A. H. Le Boiteux. *La Recherche Aéronautique*, Mar.-Apr., 1960, pp. 9–14. In French. Description of the ONERA pilot wind tunnel constructed as part of the program involving the installation of a full-scale hypersonic tunnel. The operating principles of the small-scale version are covered along with the essential parameters, measuring methods, and some experimental results.

Rotating Wing Aircraft, Helicopters

Quelques Aspects du Projet de l'Hélicoptère à Stato-Réacteurs "Kolibrie" H. 3. W. A. Kuipers. *Tech. & Sci. Aéronautiques*, Jan.-Feb., 1960, pp. 15–19. In French. Investigation of the performance and design characteristics of the NHI Kolibrie H. 3, in order to study the application of the ram-jet concept to a light helicopter.

The Helicopter as a Competitive Transport Vehicle. R. B. Lightfoot. *AHS J.*, July, 1960, pp. 3–11. Discussion comparing the helicopter with hypothetical light-weight aerial transport machines. The flight characteristics, performance, and economy of the helicopter and its derivatives–a compound and a convertiplane–are considered, and a study is made of a specific mission.

A Summary of Operating Conditions Experienced by Two Helicopters in a Commercial and a Military Operation. A. B. Connor and L. H. Ludi. *U.S., NASA TN D-251*, Apr., 1960. 15 pp. OTS, $0.50. Presentation of data obtained with an NASA helicopter VGHN recorder which represent 2,366 flights or 410 flying hours.

Helicopter-Engine Acceleration-Time Requirements Based on Pilot Demand During Recovery from Landing Flareouts. A. B. Connor. *U.S., NASA TN D-370*, May, 1960. 11 pp. OTS, $0.50. Presentation of flight measurements showing the times used by pilots to accelerate an engine from low to full power in a maneuver considered to make the greatest demand on engine-response time.

High-Tip-Speed Static-Thrust Tests of a Rotor Having NACA 63(118)A018 Airfoil Sections with and Without Vortex Generators Installed. J. P. Shivers. *U.S., NASA TN D-376*, May, 1960. 21 pp. OTS, $0.75. Investigation to determine the maximum mean lift coefficients at low tip Mach numbers and the compressibility effects at high tip Mach numbers.

Safety

The Case for the Flight Data Recorder. *Interavia*, Sept., 1960, pp. 1144, 1145. Discussion of the service which the MIDAS system might have rendered in determining the causes of several crashes, had the aircraft been fitted with such a flight data recorder. MIDAS' usefulness in providing a complete and permanent record of every important parameter throughout the life of an aircraft for the purpose of efficient repair and maintenance is also pointed out.

Structures

Initial Strains in the Matrix Force Method of Structural Analysis. J. H. Argyris and S. Kelsey. *RAeS J.*, Aug., 1960, pp. 493–495. Discussion of Grzedzielski's objection to the concept of initial strains in the treatment of cut-outs and modifications in structures.

Bars & Rods

An Investigation for the Determination of the Cross Sectional Dimensions of the Prismatic Bars in the Case of Uniaxial Repeated Loading. Orhan Ünsaç. *Istanbul Tek. U. Bul.*, vol. 12, 1959, pp. 85–98.

On a Stability Criterion for Creep. S. A. Shesterikov. (*Prikl. Mat. i Mekh.*, Nov.-Dec., 1959, pp. 1101–1106.) *PMM—Appl. Math. & Mech.*, No. 6, 1959, pp. 1574–1581. Translation. Study of the rectilinear forms of equilibrium, based on the stability of vibrations.

Kruchenie Anizotropnogo Krivogo Brusa. S. G. Lekhnitskii. *Prikl. Mat. i Mekh.*, May-June, 1960, pp. 433–437. In Russian. Study showing that the rigid theory of torsion can be generalized to cover the case of a bar having a more complex anisotropy characterized by the fact that the plane of any cross section (radial) is the plane of elastic symmetry, being, otherwise, arbitrary.

Beams & Columns

Non-Linear Bending of a Cantilever Under Several Concentrated Loads. R. Frisch-Fay. *Australian J. Appl. Sci.*, June, 1960, pp. 233–243. Presentation of an analysis of beams with "large" delfections which utilizes the geometry of the elastic shape of the cantilever rather than the solution of the basic differential equations. The particular problem of the deflection under a number of parallel loads is solved.

The Bending and Shortening Effect of Pure Torque. M. Gregory. *Australian J. Appl. Sci.*, June, 1960, pp. 209–216. Presentation of a general analysis of the bending and shortening of thin open-section members under pure torque, including also confirming experimental results.

Cylinders & Shells

Creep Deformation and Stresses in Pressurized Long Cylindrical Shells. M. P. Bieniek and A. M. Freudenthal. (*USAF WADC TR 59-399*, Mar., 1960.) *J. Aerospace Sci.*, Oct., 1960, pp. 763–766, 778.

Zur Membran- und Biegetheorie der Kreiszylinderschale für ein nichtlineares Elastizitätsgesetz. S. Tameroğlu. *Ing.-Arch.*, vol. 27, No. 6, 1960, pp. 372–384. In German. Presentation of some applications of a nonlinear elasticity theory for small distortions, in the form proposed by Kauderer, to problems involving circular cylindrical shells.

Ustoichivost' Konsol'noi Tsilindricheskoi Obolochki s Podkreplennym Kraem pri Deistvii Vneshnego Davleniia. V. M. Darevskii and R. I. Kshniakin. *AN SSSR Dokl.*, Apr. 21, 1960, pp. 1294–1297. In Russian. Study of the stability of a circular, cylindrical, ring-reinforced shell subjected to external pressure.

Elasticity & Plasticity

General Research in Flight Sciences—Mechanics of Deformable Bodies. XII—The Initial Response of an Elastic Spherical Shell to a Step Pressure Wave. P. M. Nachbar. *Lockheed Aircraft Missiles & Space Div., vol. II, TRLMSD-288139*, Jan., 1960. 38 pp. Presentation of numerical results for stresses and radial acceleration in a steel shell submerged in water. Two formulations of the problem are considered – one including interaction and one neglecting it – and the results are compared.

Continuation of Solutions of the Equations of Elasticity. J. H. Bramble. *London Math. Soc. Proc., 3rd Ser.*, July, 1960, pp. 335–353. 35 refs. USAF-supported study considering the equations of static equilibrium for an isotropic elastic body with a portion of the boundary spherical (circular). Continuations are obtained for the solutions of these equations where the displacements vanish on the spherical surface or circular arc in three and two dimensions, respectively. The case where the normal stresses vanish on a circular arc (two dimensions) is also treated.

Nekotorye Osesimmetrichnye Zadachi Teorii Uprugosti. M. Ia. Belen'kii. *Prikl. Mat. i Mekh.*, May-June, 1960, pp. 582–584. In Russian. Application of analytic functions of a complex variable to the solution of certain problems in the theory of elasticity in the case of axisymmetric deformation of bodies of revolution.

Ploskaia Zadacha Teorii Uprugosti dlia Beskonechnoi Polosy pri Zadannykh na Granitse Napriazheniiakh ili Smeshcheniiakh. S. M. Belonosov. *AN SSSR Doel.*, Apr. 21, 1960, pp. 1291–1293. In Russian. Derivation of a solution for the two-dimensional problem in the theory of elasticity for the case of an infinite strip with given stresses or displacements along the boundary.

The Plastic Coefficients for Work-Hardening Materials. W. H. Warner and P. Mahmoodi. *USAF WADC TR 59-674*, Apr., 1960. 13 pp. Evaluation of plastic coefficients in terms of material properties. The general form of the coefficients is given for various states of stress, and comparison with existing results is carried out as far as possible.

Some Relations Between the Solutions of Plane and Axially Symmetric Problems in the Theory of Elasticity and the Solution of Axially Symmetric Problems by Means of Analytic Functions. A. Ya. Aleksandrov. (*AN SSSR Dokl.*, Dec. 1, 1959, pp. 754–757.) *Sov. Phys. - Dokl.*, May-June, 1960, pp. 1378–1382. Translation.

Power Law for Creep. B. J. Rigby. *Brit. J. Appl. Phys.*, July, 1960, pp. 281–283. Presentation of a generalized form of a widely used power law for creep under constant load. The discussion is applicable to nonreversible creep phenomena or to reversible phenomena in which the recovery mechanism is negligible under load, and for which a limiting strain is reached after a long time.

A Study of Large Strains and the Effect of Different Values of Poisson's Ratio. H. Fessler and B. H. Lewin. *Brit. J. Appl. Phys.*, July, 1960, pp. 273–277. Investigation using the frozen-stress photoelastic technique to study the stresses on the inner surfaces of T-junctions of pipes subjected to different internal pressures. The peak stresses are found to be proportional to the applied pressure. The peak strains at a T-junction of hollow pipes under diametral compression were measured for identical shapes, made of materials of different Poisson's ratios. The peak strains are found to be independent of Poisson's ratio.

Fatigue

Volny Napriazheniia v Uprugoi Plite. K. I. Agurtsov. *Prikl. Mat. i Mekh.*, May-June, 1960, pp. 438–446. In Russian. Study of the dynamic stresses in media obeying Hooke's law. For materials having similar elasticity and strength limits, the points at which cracks originate can be determined. It is shown that the methods used for a free layer can be applied to the case of laminated media.

Plates

Bending of Simply Supported Rectangular Plates with Clamped Portions Along Arbitrary Sections of the Edges. M. Kurata. *Ing.-Arch.*, vol. 27, No. 6, 1960, pp. 385–416. Presentation of a theoretical solution obtained by means of determining the resisting moments introduced along the clamped portions of the edge which shall just cancel the slope of the surface of a plate. Numerical results are given for the square plates subjected to a uniformly distributed load.

The Initial Instability of an Elastic Sheet Reinforced by Stringers and Skew Ribs. G. G. Pope. *RAeS J.*, Aug., 1960, pp. 489–491. Analysis of a reinforced sheet subject to the following loads: (a) uniform direct loading normal to the ribs, and (b) uniform shear loading relative to axes perpendicular and parallel to the ribs.

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Plates With Holes

Bending Stresses Due to Temperature in Hollow Circular Plates. I. Malcolm Newman and Marvin Forray. *J. Aerospace Sci.*, Oct., 1960, pp. 792, 793. Presentation of formulas and curves for deflection, moments, and shear in a circular plate with a concentric hole subject to a linear thermal gradient through the thickness. The boundary conditions considered include cases of damped outer radius coupled with damped, simple, or free inner boundary.

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Thermal Stresses in Design. XXI—Effect of Mean Stress and Strain on Cyclic Life. S. S. Manson. *Mach. Des.*, Aug. 4, 1960, pp. 129–135. Presentation of a method for estimating the cyclic life in parts which have been subjected to tensile prestrain, considering stress components, multiaxiality, and prestrain in the plastic range.

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Spannungen in anisotropen kreiszylindrischen Rohren. K.-H. Müller. *Ing.-Arch.*, vol. 27, No. 6, 1960, pp. 417–420. In German. Analysis determining the displacement and stress conditions in an anisotropic circular cylinder with arbitrary cylindrical boundary loads. It is pointed out that a suitable relationship between the direction of the anisotropy and the load makes possible an optimal use of materials.

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Nearly Quasi-Steady Free Convection Heat Transfer in Gases. E. M. Sparrow and J. L. Gregg. *ASME Trans., Ser. C - HT*, Aug., 1960, pp. 258–260. Analysis determining the first-order deviations from the quasi-steady condition, as well as a criterion to distinguish when the heat transfer is essentially quasi-steady.

Improved Lumped Parameter Method for Transient Heat Conduction Calculations. H. G. Elrod, Jr. (*ASME-AIChE Heat Transfer Conf., Storrs, Conn., Aug. 9–12, 1959, Paper 59–HT-28.*) *ASME Trans., Ser. C - HT*, Aug., 1960, pp. 181–187; Discussion, J. S. Thomsen, pp. 187, 188. Presentation of a general mathematical method suitable for the "lumping" of many damped linear systems when the response function and the forcing function can be related by a convolution integral. The method is illustrated by application to transient heat conduction in slabs and cylindrical rods.

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A Comparison of Helicopter with V/STOL Airplanes. R. G. Ferry. *AHS J.*, July, 1960, pp. 20–23. Discussion–from the viewpoint of military needs–of the performance characteristics of helicopters and V/STOL aircraft.

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The Relative Worth of VTOL Aircraft Types R. L. Lichten. *AHS J.*, July, 1960, pp. 12–17. Evaluation of the economics of certain advanced VTOL aircraft types, if such types were developed into fully operational versions. On the basis of a technical comparison, it is concluded that advanced VTOL airplane designs cannot compete with equally advanced helicopter designs in short-range transport work. For distances over 400 miles, however, the VTOL design shows substantial advantages.

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Proceedings of the 1958 National Symposium on Telemetering, September 22–24, 1958, Miami Beach, Fla. Sponsored by the IRE Professional Group on Telemetry and Remote Control. New York, IRE, 1958. 623 pp. $5.00.

Contents: Digital Techniques: A Novel Technique for Direct Digital Conversion of Pulse-Width Multiplexed Data, F. T. Chambers. Automatic Reduction of Large Volume Test Data, I. S. Oscar and W. J. Popowsky. A Transistor-Driven Magnetic-Core Memory Using Non-Coincident Current Techniques, R. L. Koppel. A Range Time Decoder, H. A. Kirsch.

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Modulation Methods in Telemetry: Designers' Dilemma—Electronic or Mechanical Multiplexing, M. M. Kranzler. Comparison of the Performance of PAM-FM and FM-FM Telemetry Systems, D. Hochman. An Experimental Airborne PAM-FM Telemeter for Missile Applications, T. D. Lusk. The Ground Station of a PAM-FM Telemetry System, F. F. Fulton, Jr. and S. A. Schwartz. Triple FM—A Practical Method for Increasing the Capacity of Telemetering Systems, W. F. Janeway.

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Electromagnetic Wave Propagation; International Conference Sponsored by the Postal and Telecommunications Group of the Brussels Universal Exhibition, 1958. Edited by M. Désirant and J. L. Michiels. New York, Academic Press, 1960. 730 pp. $22.

Contents: Ray-Geometry Considerations for Highly Elevated Antennas, K. Toman. Über die Fluktuation des atmosphärischen Brechungsindex in Bodennähe; Ergebnisse einiger Messungen mit einem Mikrowellenrefraktometer. (On the Fluctuation of the Atmospheric Index of Refraction Near the Ground; Results of Some Measurements with a Microwave Refractometer), R. Schünemann. Researches on Backscatter of Radiowaves, I. Ranzi. Ionospheric Ray Tracing with Analogue Computer, M. S. Wong. Choix de l'Emplacement d'une Station de Base ou de Radiodiffusion en Ondes Métriques (Choice of Location for VHF Transmitters or Broadcasting Stations), I. Penninckx. On the Propagation of Correlation in Wave Fields, G. B. Parrent, Jr. Radio Wave Propagation Simulator, K. W. Otten. Ionization by Auroral Particles, A. Omholt. Diffractive Corrections to the Geometrical Optics of Low Frequency Propagation, J. R. Wait. Radiation from a Slot on a Large Corrugated Cylinder, J. R. Wait and A. M. Conda. 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Kühn (In German). Propagation Measurements at 858 Mc/s over Paths up to 585 Km, G. C. Rider. Intercomparison of Different Calculation Methods of the Sky-Wave Field-Strength, K. Rawer. On the Computation of Diffraction Fields for Grazing Angles, J. R. Wait and A. M. Conda. Sur le Rôle des Phénomènes de Réflexion dans la Propagation Lointaine des Ondes Ultracourtes (The Role of Reflection Phenomena in the Long-Range Propagation of Ultrashort Waves), F. du Castel, P. Misme, and J. Voge. Tropospheric Scatter Developments, C. L. Mackey. Ergebnisse von kombinierten Backscatter- und Impulsfernübertragungsversuchen (Results of Tests of Combined Long-Range Backscatter and Impulse Transmission), W. Dieminger, H.-G. Möller, and G. Rose. Geomagnetic Control of Ionospheric Scatter Signals, H. S. Marsh.

PHYSICS

Solid State Physics, Vol. 10. Editors: Frederick Seitz and David Turnbull. New York, Academic Press, 1960. 516 pp. $12.

Contents: (1) Positron Annihilation in Solids and Liquids, Philip R. Wallace. (2) Diffusion in Metals, David Lazarus. (3) Wave Functions for Electron-Excess Color Centers in Alkali Halide Crystals, Barry S. Gourary and Frank J. Adrian. (4) The Continuum Theory of Stationary Dislocations, Roland de Wit. (5) Theoretical Aspects of Superconductivity, M. R. Schafroth. Author Index. Subject Index.

THERMODYNAMICS

Theory of Detonation. Ia. B. Zeldovich and A. S. Kompaneets. Translated from the Russian. (Moscow, 1955.) New York, Academic Press, 1960. 284 pp. $10.00.

This volume is based on research conducted at the Chemical Physics Institute of the Academy of Sciences of the U.S.S.R.

Contents: (1) Elements of Gas Dynamics. (2) The Detonation Regime and Lossless Combustion. (3) Theory of Detonation with Losses and the Limits of Detonation. (4) The Detonation of Condensed Explosives. (5) Motion of the Detonation Products.

Flame Photometry. John A. Dean. New York, McGraw-Hill Book Co., Inc., 1960. 354 pp. $11.50.

The first ten chapters of this text and handbook are concerned with the theoretical and experimental basis for practical flame photometry. Atomization, flame characteristics, and the use of organic solvents are dealt with in detail, as are the instrumentation and technique required in practice. The remaining chapters are devoted to the consideration of the individual chemical elements that can be excited to emit radiation in a flame, and to application. There are, also, a selected bibliography, containing nearly 800 references, and an index.

The author is Professor of Chemistry, University of Tennessee.

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Index to Advertisers

★AiResearch Mfg. Divs., The Garrett Corp. 45
Aluminum Company of America 58
Astro-Electronics Div., Radio Corp. of America 61

★Bell Aerosystems Co., A Div. of Bell Aerospace Corp. ..... back cover
Bendix Corp., The
Red Bank Div. 53
Scintilla Div. 4
Boeing Airplane Co. 93
Buffalo Hydraulics Div., Houdaille Industries, Inc. 71

California Institute of Technology, Jet Propulsion Lab. 49
Continental Aviation & Engineering Corp. 68

Defense Electronic Products, Radio Corp. of America 37
★Douglas Aircraft Co., Inc. 41

Eastman Kodak Co., Graphic Reproduction Sales Div. 39

★Garrett Corp., The, AiResearch Mfg. Divs. 45
General Electric Co., Aircraft Nuclear Propulsion Dept. 73
General Motors Corp.
Harrison Radiator Div. 1
Research Laboratories 64
General Radio Co. 63
Grumman Aircraft Engineering Corp. 55

Hamilton Standard Div., United Aircraft Corp. 42, 43
Harrison Radiator Div., General Motors Corp. 1
Houdaille Industries, Inc., Buffalo Hydraulics Div. 71
Howell Instruments, Inc. 91

★Janitrol Aircraft Div., Midland-Ross Corp. 67
Jet Propulsion Laboratory, California Institute of Technology 49

Kidde Aero-Space Div., Walter Kidde & Co., Inc. 47

Lamb Electric Co., The 95

The Martin Co. 57
★Midland-Ross Corp., Janitrol Aircraft Div. 67

Radio Corporation of America
Astro-Electronics Div. 61
Defense Electronic Products 37
Red Bank Div., The Bendix Corp. 53

Scintilla Div., The Bendix Corp. 4
Space Technology Laboratories, Inc. ....
..... inside front cover
Sperry ..... inside back cover

United Aircraft Corporation
Hamilton Standard Div. 42, 43
Research Laboratories 51

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